USDA NRCS
Natural Resources Conservation Service

White River Watershed Assessment

Addison, Orange, Washington, Windsor Counties, Vermont

Third Branch Stream Classification
and
Erosion and Sediment Inventory

February 2001

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Prepared for

White River Partnership

In Cooperation with

U.S. Forest Service
U.S. Fish and Wildlife Service
Vermont Department of Environmental Conservation

Prepared by

United States Department of Agriculture
Natural Resources Conservation Service

February 2001

Cover Photo – Third Branch of the White River about 0.8 miles West of Randolph on Route 12A.

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ACKNOWLEDGMENTS

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SUMMARY

This document is a report on two separate, yet closely related, field studies conducted in the Third Branch of the White River Watershed in central Vermont. The first study is a stream classification study that utilizes two popular stream classification methods. These two methods use different approaches to define the river morphological processes that have occurred historically and continue to occur in the watershed. The second study is an inventory of erosion and sedimentation in the same watershed that provides a planning level estimate of erosion severity in the form of a sediment budget for the entire Third Branch and its major tributary Ayers Brook.

A multi-agency, multi-disciplined team was formed to gather field survey data, analyze that data and report their findings along with conclusions and recommendations to the White River Partnership (WRP). It is the hope of the assessment team that this information will assist in gaining a better understanding of the complex processes of the dynamic stream system of the Third Branch specifically and the entire White River in general. The team believes there are a number of observations and recommendations provided that can help the WRP achieve their stated mission to "... actively promote the cultural, economic, and environmental health of the White River Watershed."

In addition to a general description of the watershed as it is today this report reviews important historical events in the watershed and how they have affected the streams. The report also explains the methods used in assessing both the stream classification and the erosion and sedimentation survey. Results of these efforts are presented in both narrative and tabular form as well as being accompanied by maps and photographs. Finally, both a "Conclusions" and a "Recommendations" section is provided that highlight specific issues that need to be understood or addressed.

Among the more important issues is the significant detrimental effect of poor quality or completely missing riparian corridors in many parts of the watershed. More than one recommendation addresses various aspects of replacing riparian buffers throughout the watershed. Another finding is the determination that more than 70-percent of the erosion that reaches the stream in the form of sediment is generated by the streambanks themselves. Photographs in Appendix A show significant erosion potential along many stream reaches, some of which are not easily viewed. Most of the recommendations are generated from the premise that there are more effective and less costly remedies for degraded streams than the traditional streambank protection measures so frequently resorted to in the past. Today's approach relies on an understanding of natural stream dynamics and a process of assisting the stream in it's natural recovery from excessive erosion, occurring because of human activity or because of extraordinary natural events, to the desired dynamic equilibrium of a healthy stream. Success in implementing many of the recommendations contained in this report will depend on the ability to educate the public in general and landowners specifically about the causes of watershed problems and the most effective ways to help the streams back to better health.

White River Watershed Assessment

Third Branch Stream Classification
and
Erosion and Sediment Inventory

INTRODUCTION

This document, originally intended as a report on efforts to classify streams in the Third Branch White River watershed, has taken on an additional purpose of identifying and quantifying erosion and sedimentation in the same watershed. Early in the stream classification field work it was recognized that a planning level erosion study would go hand-in-hand with the classification work to provide a much clearer picture of the condition of the watershed.

Because both of these issues are closely related to stream morphology and to each other, they have been integrated into this single report with appropriate sub-headings under the major sections of the report.

Background

This study is a result of the White River Partnership (WRP) requesting planning assistance from the Natural Resources Conservation Service (NRCS) to conduct a variety of watershed resource related inventories and assessments. One part of a watershed resource inventory involves the streams. The focus of this study is on the streams of the Third Branch of the White River.

The WRP is a group of concerned citizens along with representatives from non-governmental organizations, local communities, and state and federal agencies. It is the stated mission of the WRP "... to develop a 'grass roots' organization that will actively promote the cultural, economic, and environmental health of the White River Watershed." Since its formation in 1994, the WRP has conducted public forums, identified areas of concern, determined evaluation criteria, ranked identified problems, obtained grant funding, and accomplished a number of streambank restoration projects. More recently the WRP has determined a need for a more comprehensive inventory of the resource conditions in the watershed to help them prioritize future projects and to generate a baseline from which to monitor progress of future treatment efforts. This broadened approach looks past the obvious, short-term, project oriented restoration actions to a more informed, long-term strategy that is conducted in a watershed context.

Purpose and Scope

The White River Partnership is concerned about the health of their watershed. One of the aims of the Partnership is to maintain and improve the health of the watershed for future generations. The primary purpose of this study is to provide information about the character and function of the streams of the Third Branch of the White River. This information is intended to be in a form that can be used by the WRP and others as a tool in planning and implementing long-term, cost-effective solutions that will help attain stream and watershed restoration goals.

A specific product of this study is a stream classification of the entire Third Branch and its major tributary, Ayers Brook. A portion of two smaller tributaries, Camp and Gilead Brooks, were also classified. Also provided is an erosion study of the Third Branch and Ayers Brook including a sediment budget (a quantitative accounting of erosion and sedimentation) which is one of the most obvious problems in the watershed. The Third Branch was chosen for study because it is considered by the WRP to exhibit many of the stream-related problems identified by the focus groups. Although areas outside of the Third Branch subwatershed were not assessed as a part of this study, it is an intended goal of this study to develop and test procedures that can be applied to other areas of the White River watershed in the future.

Assessment Team

The assessment team (See Figure 1 - Assessment Team) is a multi-agency, multi-disciplined group of federal and state agency personnel representing NRCS, U.S. Forest Service, U.S. Fish & Wildlife Service, and the Vermont Agency of Natural Resources. Disciplines represented on the team are biologist, geologist, planning engineer, hydraulic engineer, environmental engineer, hydrologist, and district conservationist. A sedimentation geologist from the NRCS National Soil Survey Center specializing in fluvial geomorphology provided on site direction during part of the study.

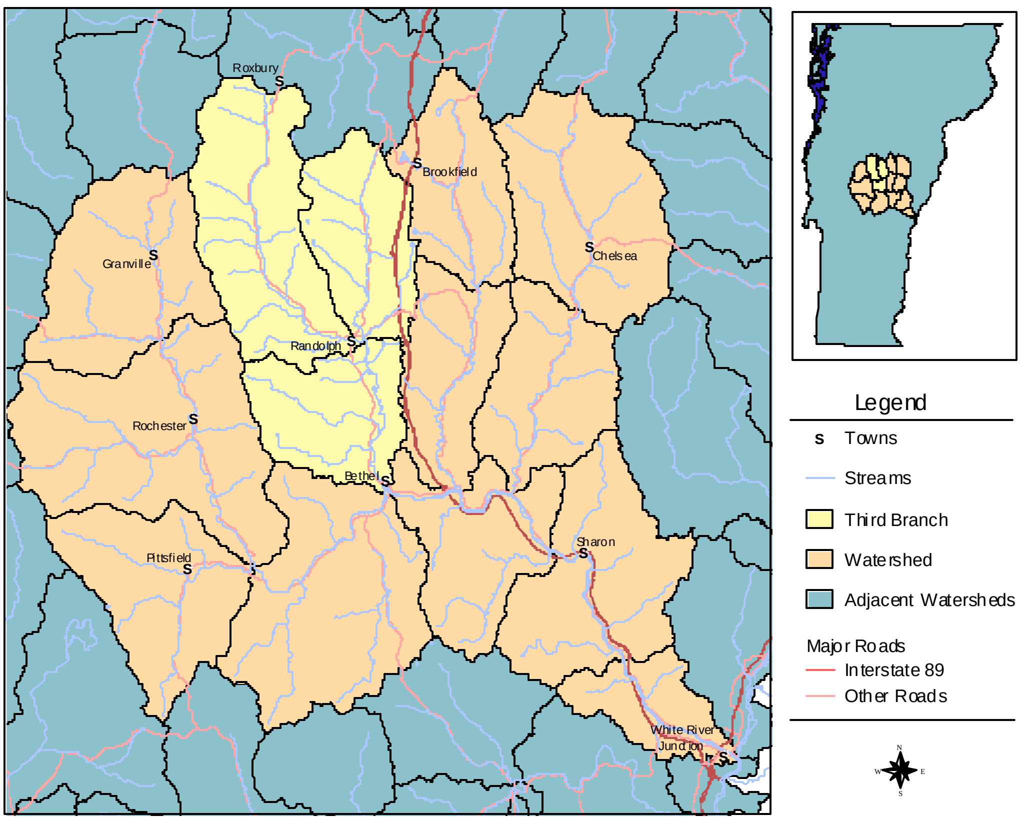
Figure 1 - Assessment Team

SETTING AND PROBLEM

Watershed Description

The White River Watershed (See Figure 2 - White River Watershed Map) is located in central Vermont and drains 710 square miles or about 454,400 acres. The major portion of the watershed lies in Orange and Windsor Counties, with relatively smaller portions of the western part of the watershed in Washington, Addison, and Rutland Counties. The Town of Randolph is in the middle of the upper part of the watershed while White River Junction, a part of the Town of Hartford, is at the narrow outlet of the watershed where the White River joins the Connecticut River.

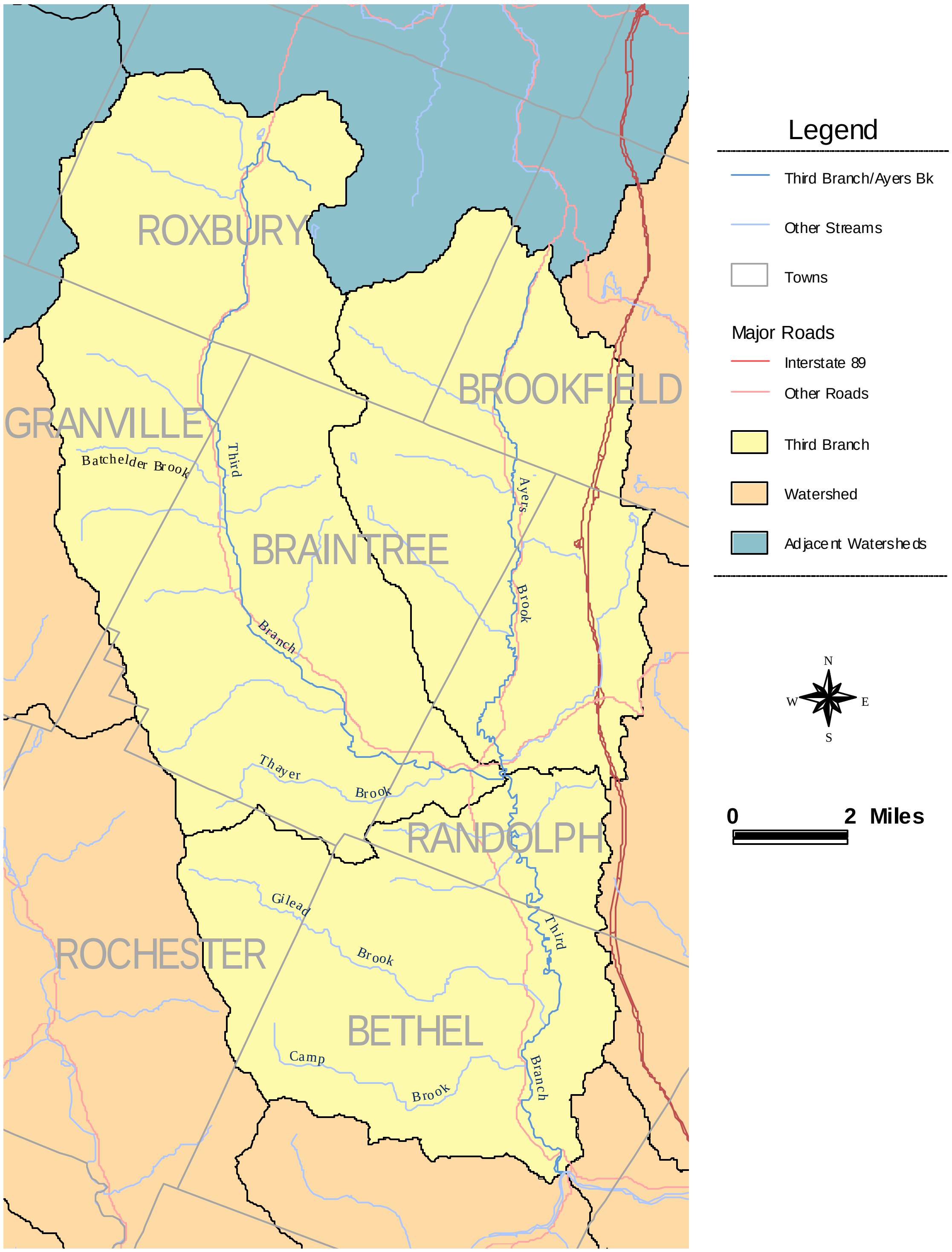
Figure 2 - White River Watershed Map



The upper part of the White River along with its three largest tributaries, the First, Second, and Third Branches, flow generally to the south, with the lower part of the White River flowing east as it collects the tributaries and then southeast to join the Connecticut River. The channel distance of the White River is 57 miles long while the channel distances for the First, Second, and Third Branches are 22, 24, and 27 miles respectively.

The Third Branch subwatershed (See Figure 3 - Third Branch Subwatershed Map) has a drainage area of 136 square miles with headwaters just south of the town center of

Figure 3 - Third Branch Subwatershed Map



Roxbury, Vermont. The Third Branch flows south and then southeast to Randolph where it is joined by its only major tributary, Ayers Brook, and then south again to meet the White River at Bethel. The upper portion of the Third Branch, upstream of Randolph, is characterized by large swampy areas in a floodplain confined by steep mountain slopes. Downstream of Randolph, along the Third Branch and also on much of Ayers Brook, a considerable amount of agricultural activity occurs on a somewhat broader floodplain with mountain slopes flanking both sides of the valley.

The Third Branch has an average slope of only 0.3 percent and descends 480 feet in its entire length. This is in stark contrast to the numerous very steep short tributaries that fall up to 2,000 feet in about one mile to feed the Third Branch in the upper half of the watershed. Nearly all of Ayers Brook also has a gentle slope, averaging 0.4 percent, as well as steep mountainside tributaries; however, the mountains are not as high nor as steeply sloped as those of the Third Branch.

Geology

Bedrock geology of both the Ayers Brook and Third Branch watersheds is comprised primarily of metamorphic rocks. The dominant rock types are quartz-mica schist, phyllite, carbonaceous slate, quartzite and recrystallized limestone of Ordovician and Devonian age. The orientation of the bedrock imposes structural control on the stream valleys. Rock outcrops along the rivers and streams impose strong lateral control on some reaches of the meandering river. Rock outcrops at Bethel exerted grade control to the river system before the dam was built. The bedrock is highly resistant to stream erosion.

Glaciofluvial or glacial lake deposits dominate the lower reaches of Ayers Brook and the portion of the Third Branch watershed downstream of Randolph. These glacial deposits range from very fine silt and silty clay to fine sand and gravel. Long reaches of the Third Branch pass through these deposits.

Glacial outwash deposits dominate the Third Branch upstream of Randolph. These deposits, formed by the action of glacial meltwater are coarser sand and gravel. They contain a smaller portion of silt than the glacial lake deposits.

Alluvial deposits of sand and gravel are found in the immediate stream channels and some adjacent areas where higher velocity flows have deposited them as overbank deposits. These alluvial deposits range from silt and sand in lower velocity areas to coarse sand gravel and cobbles in high velocity regimes.

Glacial till deposits of unsorted gravel, sand, silt, and clay size particles dominate the uplands in the watershed. Where the till borders the stream channel, it also imposes lateral control on the river system, being more resistant than the silt, sand and loose gravel of glacial lake and outwash deposits.

Tributaries to the main Third Branch and Ayers Brook flow mostly on glacial till and bedrock. The smaller size of their watersheds and the fact that the glacial till is more resistant to erosion result in lower streambank erosion rates.

Soils

Several factors, including geology, landscape position and slope steepness, result in a large variety of soils in the Third Branch watershed. Downstream of Randolph, the east and west sides of the valley contain different soil associations. On the east side, where the soils are not as acidic due to limey layers in the bedrock, Vershire, Glover and Buckland soils predominate. The Vershire and Glover soils are in rocky and ledgy areas, while the Buckland soils are in broader open areas and are wetter. On the west side of the valley, more acidic Tunbridge, Lyman and Berkshire soils are common.

After the Third Branch splits with Ayers Brook in Randolph and heads upstream to the northwest, the Tunbridge, Lyman and Berkshire soils are on both sides of the valley. Tunbridge and Lyman are also in rocky and ledgy areas, while Berkshire soils, deeper to bedrock, are scattered throughout the uplands.

In the valley itself, sandy Windsor and Agawam soils are common on terraces. Many town centers and agricultural fields are on these soils. The alluvial floodplain soils include Limerick and Winooski soils.

The Third Branch is the western boundary of the eastern Vermont "hill farm" country. The steep slopes and loamy textures of many of the soils in the watershed increase the potential for erosion in the uplands.

Erosion Types

Sheet and rill, gully, and streambank erosion are all types of erosion normally estimated for a watershed erosion inventory. Erosion of dirt road surfaces, although calculated separately, is classified as sheet and rill erosion.

Soil erosion is a natural geologic process. Geologic rates of erosion are a necessary part of the soil forming cycle. When rates of erosion exceed geologic rates there is reason for concern. Some indicators of excessive erosion rates are deep rills in crop fields, raw and bare streambanks, sediment-laden water, and development of midchannel bars.

Erosion that exceeds geologic rates is usually induced by human activity. Intensive cropping, increased watershed development and road construction usually result in excessive erosion. Excessive streambank and channel erosion is caused by stream corridor manipulation such as channel straightening, gravel dredging, or encroachment on the natural floodplain and changes in runoff resulting from watershed activities.

Sheet and rill erosion occurs when rain falls on the land and causes soil particles to dislodge. Rills form small channels, which carry away fine-grained sediment. These sand and silt particles are carried down slope through the delivery system of rills to a receiving stream, pond or river.

As the rills grow larger, the ability of the delivery system to transport more sediment grows. Left untreated, deeper and larger rills become gullies capable of transporting larger amounts of sediment.

Deep channels that are maintained by concentrated flow during and immediately after rainstorms typify gully erosion. Normally, gullies do not exhibit perennial flow unless they intercept groundwater and springs develop. The concentrated flow in the gully causes widening and deepening. Gully erosion, although present, is not a major erosion contributor in the Third Branch watershed.

Streambank erosion is also a natural geologic process in the landscape. Streams and rivers occupy different positions in their floodplain over time due to the natural meandering process. The geologic rate of streambank erosion is a balance of sediment supply and the carrying capacity of the river or stream. This dynamic equilibrium in pristine watersheds developed over many thousands of years since glacial retreat in the Northeast.

Erosion from dirt road surfaces is evident in the Third Branch watershed. There are about 119 miles of dirt roads throughout the watershed. Roadbed erosion is calculated through use of sheet and rill erosion equations.

Sediment Delivery

Erosion dislodges soil particles from tilled earth resulting in the reduction of soil quality. At that point, the sediment has entered the transport system. Once the soil particles are in transport, they eventually reach a water body where they add to the sediment load in the stream system. Based on experience, geologists estimate a delivery ratio based on the type of erosion and its proximity to the receiving water body. For example, sheet and rill erosion is assigned a lower delivery ratio if the fields are further from readily accessible avenues of transport. Streambank erosion is assigned a higher delivery ratio because the eroded sediment is immediately adjacent to the river. Gully erosion can also have a high delivery because gullies are usually adjacent to stream channels. These sediment delivery ratios are based on judgement developed over time and are reasonable estimates. The ratios can be checked by measuring sediment accumulated at, or removed from, the receiving water body either behind an impoundment or in the bottom of a pond. Sediment delivery curves based on the size of watershed and various transport equations can be used to refine the data. For the purposes of this study, an estimate is the best way to illustrate the relative contribution of different sediment sources. The estimates are not meant to be exact calculations of the tons of sediment in transport and should not be used in that fashion.

Land Use and Erosion Rates

Land use mapping in the watershed is incomplete at this time. Land use percentages were estimated from the maps used in calculating sheet and rill erosion. These maps show that approximately 90% of the area is wooded, 2.5% is tilled agriculture, 5% is hay and pasture and 2.5% is non-eroding paved and urban land. Generally, forested land in the watershed has a low erosion value of about 0.1 ton per acre per year due to forest canopy. If logging is minimal, as it appears to be in this watershed, logging roads do not contribute much sediment to the total.

Agriculture in the watershed is mostly dairy farming, resulting in row crop corn as the predominant tilled land use. Hayland is the other primary land use and contributes very little sediment per acre compared to the other land uses. The amount of erosion from tilled land was estimated at 2 tons per acre per year and that from hayfields at about 0.1 tons per acre per year.

Land use along the Third Branch and Ayers Brook is in some ways well suited to a meandering river system. Unfortunately, the landowners along the river may not see it that way. When the flood of June 1998 swept through the area, large portions of streambank along the golf course were eroded away; farmland riverbanks were washed away; electric transmission lines were threatened; and small farm bridges were washed out. This represents major changes in the stream alignment. Based on existing land use this is a predictable result of flooding.

Previous Study

The Soil Conservation Service did a study of eroding sites in 1976 (Cook, 1976). This study consisted of field inspection and data collection on critically eroding sites along the Third Branch and Ayers Brook. Stream lengths and heights of eroding bank were estimated. An estimate of the amount of riprap required to treat the eroding areas was made. Photographs, which accompany the report, are valuable to show changes in bank morphology over time as well as the total length of actively eroding streambank. This study provides excellent documentation of what erosion conditions were at the time.

Watershed History and Effects

In the course of history, there are many factors that can bring about change to a stream system. These disturbances can be in the form of natural disturbances such as floods, hurricanes, tornadoes, fire, volcanic eruptions, earthquakes, insects and disease, landslides, temperature extremes, and drought. Although natural events can bring about high energy disturbance, in many instances the ecosystems can recover and regenerate on their own.

Human intervention initiated change in the White River watershed, as it did in many New England river systems. Human induced disturbances brought about by land use activities have the greatest potential for introducing long lasting change to a stream corridor. Physical disturbance is the most common type in the watershed. In the White River these changes which occurred throughout history in the watershed are: forest clearing, cultivation, building of transportation infrastructure such as railroads and highways, streambank armoring, gravel mining, dams, and urban development. History has shown that these activities have a much greater potential for producing long lasting changes to the ecological structure and functions of stream corridors.

Agriculture, Roads, and Railroads

Vermont was settled in the 1700's through early 1800's. Early roads followed the drainage systems as farmers cleared the floodplain forests and began haying the newly created meadows to feed farm and pack animals. Railroads soon followed the major roads. Fill was typically required to keep the roads and railroad line out of the annual snowmelt floods. The terrain was rocky and hilly, and the floodplains narrowed at places where the rock closed in from both sides of the valley. Road fills encroached on the floodplains, especially in the narrows.

Farmers were also prone to moving the smaller channels from the middle of the valley floor off to one side to improve access to their fields and to increase the acres they could farm. These disturbances probably caused the channel to widen to carry the faster moving runoff due to channel straightening, the loss of riparian vegetation, and the loss of floodplain area. In certain locations, the channels widened instead of downcutting due to the large size of the gravel and cobble particles lining the riverbed. The cobble materials may be remnants of higher flows that occurred after the last ice age. It was easier for the river to erode the smaller size sediments in the riverbanks than to cut down through the gravel and cobble bed.

The acreage of arable land has probably not increased much today over that present at the turn of the century. However, there is probably more row-cropping occurring on the valley floors today. The level of livestock grazing may also be about the same today as at the turn of the century. Consequently, the riparian corridor vegetation is still in relatively poor condition compared to the pre-settlement riparian forests. Even though the river is likely no longer responding or adjusting to the historic disturbances of the 1700's, accelerated bank erosion does still occur today due to the poor riparian corridor condition. There are numerous examples in the Third Branch subwatershed of incised channels going through the widening stage by eroding their channel banks.

Logging and Reforestation

Logging was the principal industry in the state through most of the 1800’s. Photographs indicate that forest cover was essentially gone by the late 1800’s. With the loss of the trees and the forest duff layer, and the increased density of logging roads in the steep uplands and on the valley walls, runoff volume must have increased significantly, and the patterns of runoff probably changed. Sediment loads delivered to the river systems also increased. The rivers responded to these additional disturbances by enlarging their capacity through widening.

Today, about 75 percent of the forest cover has reestablished. The volume of runoff probably dropped significantly compared to 1900, and the patterns of runoff are also more similar to the pre-disturbance patterns. It appears that the rivers have adjusted their cross-section and slope to the changed hydrologic conditions due to the loss and recovery of the forests. The annual peak flows for various storms for different time periods for the Ayers Brook stream gage at Randolph and the White River gage near West Hartford were examined to check this hypothesis (See Table 1 - Historic And Recent Annual Peak Flow). The Ayers Brook gage exhibits almost identical peak flows for the different time periods. The more recent time period for the White River near West Hartford actually shows significantly lower peak flows for the less frequent events compared to the 1916-1956 period. However, the 1.5-year peak flow is only 11 percent less than the peak for the older time period. Based on these numbers, it is doubtful that the White River Watershed rivers are still adjusting their dimension and form due to the disturbances of the changes in historical forest cover.

Table 1 - Historic and Recent Annual Peak Flow

Stream Gage/ Time Period (Yrs)	Return Interval (Years)					
	1.5	2	5	10	50	100
	Annual Peak Flow (cubic feet per second)					
Ayers Brook @ Randolph VT						
1940-1969	590	717	1,060	1,320	1,970	2,290
1970-1996	585	715	1,050	1,300	1,930	2,230
1940-1996	590	717	1,050	1,300	1,930	2,230
White River near W. Hartford VT						
1916-1956	15,600	19,200	29,300	37,100	57,900	68,200
1957-1996	14,000	16,500	23,200	28,000	40,000	45,700
1916-1996	14,800	17,800	26,300	32,700	49,200	57,200

<u>Gravel Mining</u>

From 1972 to 1986, a new disturbance occurred in a portion of the White River Watershed. Unregulated gravel mining resulted in hundreds of thousands of cubic yards of gravel being removed annually from bars in the Third Branch. The loss of bed material and the removal of the bed structure disturbed the river system. Stable rivers are in dynamic equilibrium. They erode their bed and banks, and they deposit sediments, but the average annual quantities and rates of these geomorphic processes are very low. The amount of gravel in the riverbed equals the amount delivered to the river from its watershed and bank erosion minus the amount transported downstream each year. The quantities and rates of addition and subtraction of gravel balance out in a stable river. Gravel mining disrupts this balance.

Stable rivers maintain a balance between their energy (channel slope and the quantity of water in the channel) and their load (size of bed material and quantity of bed material moved). After a few years of mining the bars in the Third Branch, the amount of bed material available to move was drastically reduced, and the river became unstable. In response to the change in balance, the river began to erode its bed and banks in an attempt to bring its sediment load back into balance with its slope and the amount of water in the river.

The removal of gravel from the point bars in the river also disturbed the spacing of pools and riffles. In a stable, gravel-bed river, the spacing between pools or riffles is 5-7 bankfull channel widths. The pools form in the apex of each meander, and riffles form in the crossover area midway between two meander apices. Pools and riffles help dissipate and distribute energy uniformly in a river. They help move sediment through the system and maintain channel stability. Pools and riffles are also important aquatic habitat components.

The removal of gravel from the point bars in the river also caused the loss of low-flow and bankfull flow sinuosity. Sinuosity is a measure of how curvy a river is. If the distance from point A to point B in a valley floor is 1,000 feet and the river distance between the same two points is 2,000 feet, the river has a sinuosity of 2.0 (2,000 feet of river length/1,000 feet of valley length). In a stable system, the point bars confine low flows to the thalweg of the channel. The thalweg is a line connecting the deepest points in a riverbed from an upstream to downstream direction. The deepest points in a stable river are in the pools at the apex of each river meander, so the low-flow channel is highly sinuous as it moves from one side of the river to the other. The low flows become oxygenated as they flow over the riffles, and they deliver this oxygenated water and any food material that has fallen into the river to aquatic life taking refuge in the deeper, cooler water of the pools.

Research indicates that most of the bedload moved by a river over a long period of time is moved by a high frequency flow (1-3-year return interval). It is true that rivers during major floods move great amounts of sediment, but the major floods occur infrequently. It is the higher frequency flows that do most of the work in stable river systems. This high frequency flow has been called the stream-forming discharge because it maintains the channel cross section dimensions required to move bedload. In a stable river, this flow has been called the bankfull discharge since the elevation of the top of the bank typically coincides with the elevation of the active floodplain adjacent to the river.

The gravel bars in the Third Branch are typically submerged during the bankfull discharge so the flow path is straighter than during low flows. The structure of the bar remains intact, however, and bedload transport is facilitated by this bar structure. After mining, the gravel bar structure is removed and, when a discharge occurs that matches the former bankfull discharge, its flow is shallower as it spreads across the wider bed. The shallow flow cannot transport as much bedload as the deeper bankfull flow did prior to removal of the bars, so bedload deposits build up randomly and obstruct the flow and change the angle of flow into the streambank. The bank typically erodes under this changed angle of flow, which widens the river even more and exacerbates the random deposition and erosion patterns.

The gravel bars in the Third Branch also help maintain channel stability during flood events. The bars typically erode away as the channel fills with water during storm runoff. The removal of the point bars in a high flow situation results in a straighter path of flow, less resistance, and a more efficient channel to move the greater water and sediment loads occurring during the high flow event. The straighter flow path also relieves the erosive pressure on the banks. In a stable river, as the peak of the flow passes, the point bar rebuilds on the receding limb of the storm's hydrograph. The bars rebuild as the flow decreases, and they help the river maintain its stability by reestablishing its pools and riffles.

These flood-flow channel changes do not occur if the gravel bars are removed. The energy that was dissipated during erosion and rebuilding of the bars does not occur. Instead, the flood flows can severely erode the banks and scour the riverbed in an attempt to dissipate energy.

As described above, the change in channel dimension and pattern due to gravel mining typically results in accelerated erosion and deposition processes. Unfortunately, in the wider channel bottom the newly deposited sediment is typically finer and can infiltrate the coarser sediment remaining in the river bottom. As the pore spaces in the coarse sediment fill with fines, spawning habitat is physically lost. The remaining habitat is degraded due to the decrease of oxygenated flow through the river bottom sediments.

Riparian Corridor

One overriding feature that is conspicuous by its absence throughout the watershed is that of a good riparian corridor. A tree and shrub vegetated corridor acts to stabilize streambanks and hold the soil in place during large storm events. Other benefits from the presence of healthy riparian vegetation include reduced delivery rates of sheet and rill erosion and interception of pollutants from other non-point sources. It is likely that the disturbance of this corridor during the initial clearing of the land followed by road and railroad building began the process of excessive erosion along the streambanks in this watershed. Development and maintenance of a healthy riparian corridor would serve multiple beneficial purposes.

In the Third Branch of the White River there is additional evidence of human activity. Railroads came to the valley of the Third Branch in the 1850's, later followed by unpaved and then paved highways. These effects are likely some of the main reasons the rate of erosion in the watershed exceeds geologic rates.

Periodically, major storm events ravage the watershed. One such storm on the Third Branch in June 1998 caused major erosion of streambanks, downcutting of channels and rearranging of meanders in the river system. Since these are such severe events, often the reaction is to try to protect further damage to infrastructure by building retaining walls, installing rock riprap, or building structures to slow the force of water. Unfortunately, the best-intentioned projects can have a negative effect on the river, increasing the likelihood of greater damage in the future.

Paved highways, parking lots and development in the watershed increase both the amount and speed with which water runs off the land. Logging and removal of vegetative cover from what was once a forested landscape increases runoff. Rainfall events of similar magnitude to those in the past can create greater flooding due to greater paved area creating faster runoff and less infiltration. When retaining walls and other river controlling structures are built, the floodplain is restricted, giving the channel less space to meander. During flood flows, the energy developed by a river exerts itself in areas that were not protected creating damage in those areas. Where a river channel is restricted and entrenched and thus removed from its floodplain, the ability of the floodwaters to spread out over the floodplain is restricted and greater damage is done within the channel. Large storms now cause greater damage due to these factors.

Installed Streambank Protection

Over the years, streambank protection in the form of rock and boulder riprap has been installed throughout the watershed to protect roads, farm fields, golf courses and houses from the meandering river (See Figures A1 & A2 in Appendix A). Most of the riprap has been installed on banks between 6 and 10 feet high. In two locations near Bethel, riprap has been compromised and is in disrepair. The river has meandered behind and around the rear of the rock and formed a new channel. New installations of riprap were also constructed in response to the June 1998 storm. Locations of all known riprap sites are identified in the erosion study database and inventory maps (See Appendix B).

<u>Floods of 1973 and 1976</u>

Soon after gravel mining began in earnest in 1972, a flood deposited mounds of bedload in the mined reaches and the diverted flows caused serious bank erosion problems. A similar event in 1976 created the same problems. In order to regain capacity for future floods, gravel and cobble bed material was scraped from the river bed and pushed up onto the banks and floodplain along the Third Branch between Riford Brook and the first dam in the city park on the west edge of Randolph. Usually this type of practice fails as the river reclaims the pushed-up material and attacks the banks again. It appears that this did not happen to the “windrows” of gravel and cobble along the Third Branch. The “windrows” contained material too large for subsequent flows to move, and they became stabilized by woody vegetation. Today the river appears to be stable in this reach, but its form and pattern have been altered from its pre-gravel mining condition due to the “armoring” of its banks and filling of its floodplain by the gravel and cobble “windrows”.

<u>Urbanization</u>

Most of the city and town sites in Vermont are over 200 years old. There has been continued growth of most of the cities and towns over time, and some rural areas have experienced a land use change to rural subdivisions. On the East Coast of the United States, it has been shown that if 10 percent of a river’s drainage area is converted from agriculture or forest to impervious cover, the river's hydrology will change resulting in a change in the dimensions of its cross section (Schueler, 1995). It appears that the White River Watershed has not experienced that level of conversion within the past 20 years, so the rivers do not appear to be adjusting to that type of disturbance.

Description of Problem

Because of the finite human and financial resources available to the WRP, future actions need to be identified and prioritized in order to maximize the benefit to the social, economic and ecological communities of the watershed. An effective, comprehensive plan to halt or reverse the deterioration of various aspects of the streams in the watershed is needed. ***<u>The problem</u>*** is that a better understanding of the complex processes of the dynamic stream system is needed before such a plan can be developed. This study provides an important step by obtaining critical field measurements and analyzing that data within a widely recognized stream classification system. Stream classification provides a basis for understanding what is happening to the stream and, therefore, what may work best to return it to a desired state of dynamic equilibrium.

ASSESSMENT METHODS

Stream Classification

The relationships between streams and their watersheds are complex. The use of a stream classification system is an attempt to simplify some of these relationships so that the classification system becomes a type of "language" that promotes communication among the varied disciplines interested in stream restoration. Another advantage of conducting a stream classification is the focus placed on the channel forming or dominant processes in the entire stream system. The determination of various stream types throughout the watershed allows one to consider the landscape context of the stream system and extrapolate inventory data over a broad geographical area.

Two classification systems were utilized in this study. The Rosgen (1996) stream classification system is very comprehensive and in common use by many agencies and organizations throughout the country. The Schumm (1984) Channel Evolution Model (CEM) is less complex in its field data collection requirements but has flexibility in the assessment of both natural and constructed channels. The CEM allows stream processes and channel stability to be more easily understood by a public not trained in stream morphology.

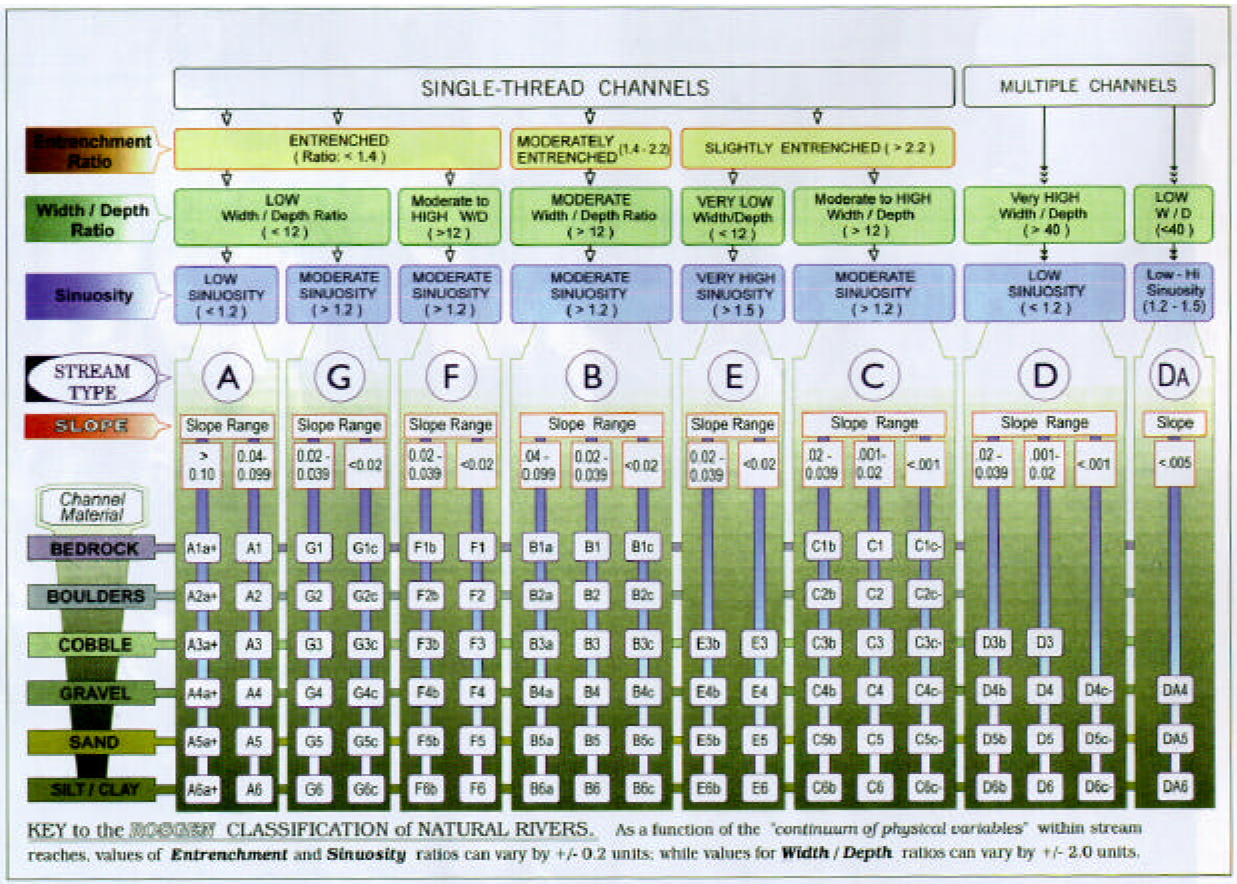
Rosgen Classification - Level I

The stream assessment team used the Rosgen Stream Classification System that is based on morphological characteristics of the stream. Rosgen's Level I is the first of four levels of a hierarchy of complexity that builds on findings in previous levels. More specificity in data requirements and related interpretations of stream reaction to disturbance is required when advancing from Level I to Level IV. Before undertaking the task of field measurements of the several characteristics necessary for a Level II stream classification, a Level I classification was conducted. A Level I classification is primarily done in an office setting using topographic quadrangle maps, aerial photos, and some local knowledge. It relies on minimal fieldwork and is primarily based on landscape setting (uplands versus valley floor), slope, and sinuosity. The stream assessment team recorded the Level I reaches on a map and compiled a table of slopes computed from topographic quadrangles and sinuosity from aerial photos and quadrangle maps.

During initial office measurements (Rosgen Level I), almost the entire Third Branch was classified as a C stream type (See Figure 4 - Rosgen Stream Channel Classification System). Ayers Brook was determined to be an A or B stream type near the watershed divide and an E or C stream type for most of the reach in the valley floor setting.

Because the depth of the streams and entrenchment ratios were not yet measured, it is generally not feasible to identify other stream types at Level I. However, the Level I inventory can be used to help determine where to look for transitions in stream types, and it can be used as a base map to help extrapolate Level II findings. The full list of major stream types in the Rosgen Classification System is shown below (See Table 2 - Rosgen Major Stream Type Descriptions).

Figure 4 - Rosgen Stream Channel Classification System



Note: Reproduced with author's permission (Rosgen 1996).

Table 2 - Rosgen Major Stream Type Descriptions

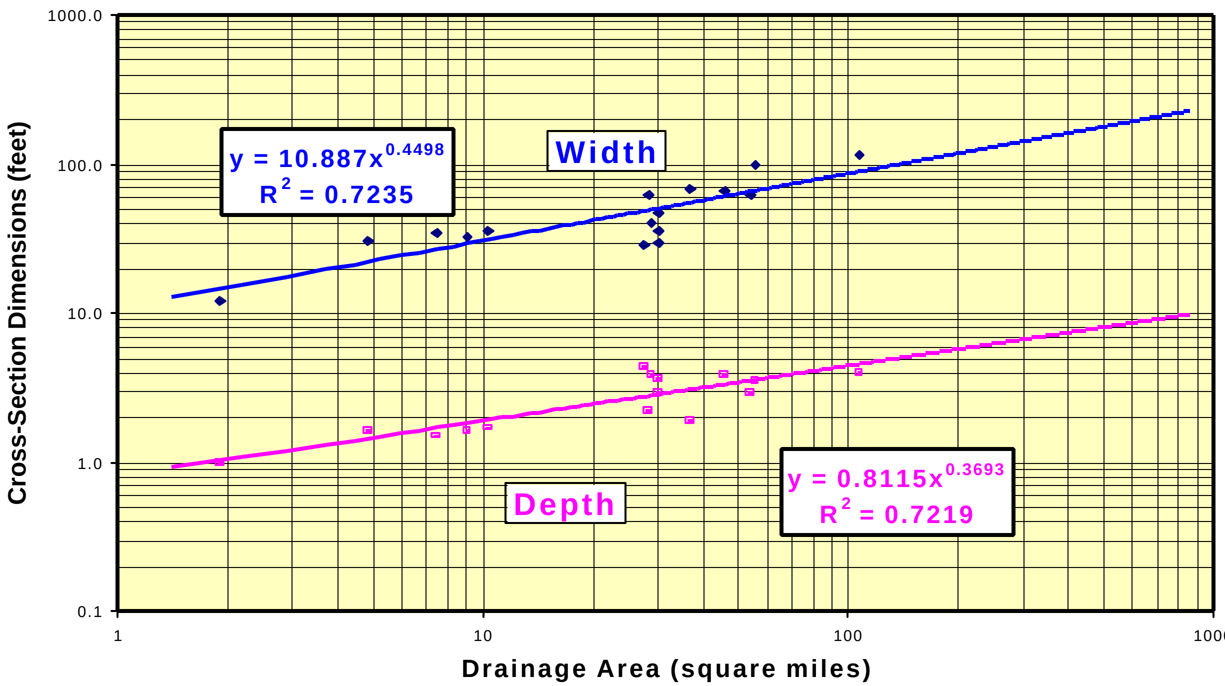
Stream Type	General Description
A	Steep, entrenched, cascading, step/pool streams. High energy/debris transport associated with depositional soils. Very stable if bedrock or boulder dominated channel.
B	Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable plan and profile. Stable banks.
C	Low gradient, meandering, point-bar, riffle/pool, alluvial channels with broad, well defined floodplains.
D	Braided channel with longitudinal and transverse bars. Very wide channel with eroding banks.
E	Low gradient, meandering riffle/pool stream with low width/depth ratio and little deposition. Very efficient and stable. High meander width ratio.
F	Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.
G	Entrenched "gully" step/pool and low width/depth ratio on moderate gradients.

Rosgen Classification - Level II

Rosgen's Level II classification involves measuring bankfull channel cross section dimensions, channel slope, and flood-prone width in the field. Field measurements can also include a determination of stream sinuosity by dividing the slope of the valley floor by the channel slope. This measurement was made on Ayers Brook at the riding stable to compare results with the office technique. The result (1.6) compared favorably with the numbers measured from the topographic quadrangles (1.56) and the aerial photos (1.63). A Level II classification also includes a Wolman (1954) pebble count to determine the dominant size of bed material at the cross-section site. Pebble counts are time consuming and were not done at all cross section locations. Field data sheets were completed for each section surveyed.

The bankfull width and depth relationship of a classified stream can be plotted as a function of drainage area (See Figure 5 - Bankfull Width and Depth Relationship). This graph is a plot of drainage area versus the bankfull widths and depths of the streams classified during the field assessment. It shows that the measured values plot fairly close to the fitted curve and that there is a good relationship between the measured cross-section dimensions and drainage area.

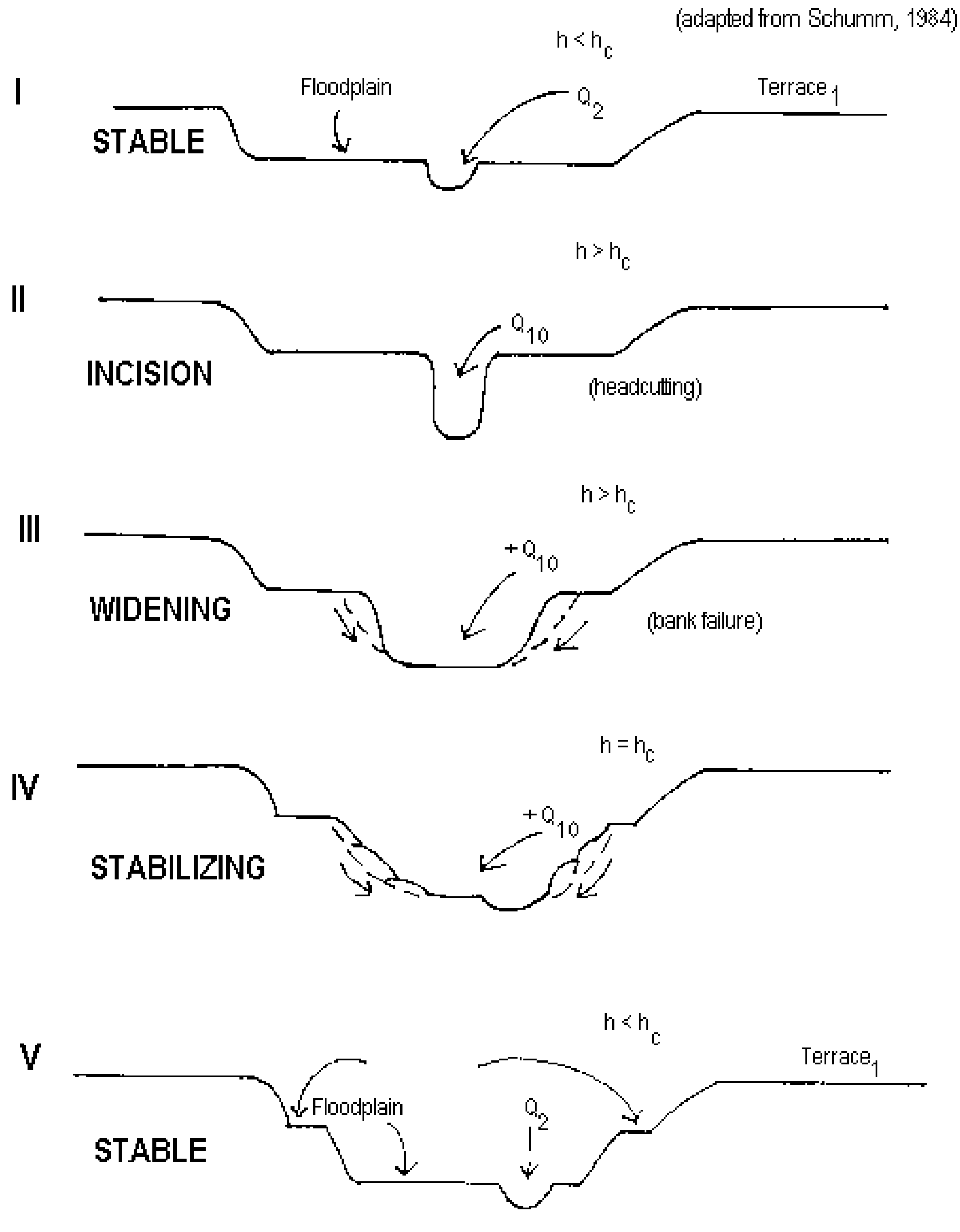
Figure 5 - Bankfull Width and Depth Relationship



Channel Evolution Model (CEM)

While Rosgen's classification system is appropriate for defining stream morphology, especially for natural or relatively undisturbed streams, Schumm's CEM (See Figure 6 - The Five Stages of Channel Evolution) is well suited for natural and constructed

Figure 6 - The Five Stages of Channel Evolution



h = streambank height

h_c = critical streambank height (slope failure is imminent depending on the strength of the soils in the bank)

channels in identifying disturbed or undisturbed stable channel conditions. Placing a stream in one of the five stages of channel evolution involves identifying the relative elevations of the top of the bankfull channel, the active floodplain, and any terraces (Stages I or V). Once those relationships are determined, the bottom is inspected for evidence of downcutting (Stage II) and the banks are inspected for active sloughing (slope failures) (Stage III). A new active floodplain forming below an abandoned floodplain, a terrace, marks Stage IV. As a headcut or knickpoint (Stage II) moves upstream through a watershed, Stages III, IV, and V follow. Tributary streams also go through the evolution process as a headcut moves past their confluence with the main stem. There is a correlation between Rosgen stream types and the Schumm five stages of channel evolution (See Table 3 - Schumm CEM Stage/Rosgen Stream Type Correlation). Stages of channel evolution are often represented by certain morphological types as described in the Rosgen classification system which in turn have a predominant sediment regime.

Table 3 - Schumm CEM Stage/Rosgen Stream Type Correlation

Schumm CEM Stage	Rosgen Stream Type	Sediment State
I	A B C D E	Erosion Transport Deposition Deposition Transport
II	G	Erosion
III	C F	Deposition Erosion
IV	C	Deposition
V	C E	Deposition Transport

Field Surveys

Field surveys were conducted during the Spring and Fall of 1998 and again in the Spring of 1999. The objective was to gather detailed information at representative reaches of the Third Branch White River, Ayers Brook and selected tributaries to classify the Third Branch subwatershed streams at a Rosgen Level II intensity. In many ways the Level II field surveys are a verification of, and modification to, the Level I classification discussed earlier.

The field activities involve a number of steps that include site selection, stream cross section and profile engineering surveys, and identification of bank and bed materials. Locating a suitable survey site meant finding a location that was representative of the reach being classified that is stable, not affected by bridges or other disturbances, of sufficient length, and accessible with the equipment available to the assessment team. In some cases hip or chest waders were necessary while in some locations a boat or canoe were required. Site selection can also be significantly affected by the objectives of the classification effort. For instance, one may want to establish a reference site, a long-term monitoring site, a site to document a specific local disturbance, or detailed classification reaches for the purpose of restoration implementation activities. For this study site locations were fairly widely spaced to allow for broad coverage of the subwatershed yet still have at least one or more survey sites per classification reach.

The procedure at each survey location was to walk the stream in both the upstream and downstream direction to insure that the requirements of the site were met and at the same time identify the critically important "bankfull" indicators. Once a determination of the bankfull elevation at the cross section location was made, a tape was stretched from bank to bank at that elevation, and cross section measurements were taken using a laser level and survey rod. Additional floodprone widths are measured, and in some cases Wolman pebble counts were conducted to get an accurate determination of streambed material in the reach. A decision was made to survey additional cross sections at the expense of doing pebble counts at all locations. This tradeoff is considered appropriate based on the current objectives of the classification effort. Where bed material has been estimated with either abbreviated pebble counts or other "judgments", that fact is noted in the data sheets and in the stream classification table.

Erosion and Sedimentation Survey

The methodology used in the field was a combination of traditional erosion estimation techniques developed by Soil Conservation Service (now NRCS) researchers and adapted and modified for use through years of fieldwork by SCS geologists throughout the country (USDA, 1966, 1977, 1983, and Renard et.al., undated). The techniques, in good portion, are based on solid observation and experience of the observer.

It is worthwhile to note that the new data collection technologies used are simply tools that better enable the field team to gather data. The experience of trained observers is critical to the estimation of the amount of erosion and conditions along the river.

Procedures

Before field data collection was undertaken, an existing data search was performed to determine what natural resource information already existed in the Third Branch watershed.

An online set of historic topographic maps scanned by the University of New Hampshire was used to better understand the changes that have occurred through time. These maps proved useful in studying the meandering pattern of the river.

Since this study is, in part, a demonstration project, it was decided by the assessment team to undertake a digital data collection procedure using an appropriate streambank erosion classification methodology. If successful, this technology could be transferred to similar studies throughout the watershed.

The first step was to devise a methodology to classify the streambank data. Several erosion studies completed in the northeast were evaluated and compared. Various evaluation factors were selected based on experience in similar watersheds. Rosgen's streambank erosion indicators were also incorporated. A streambank ranking system (See Table 4 - Riverbank Erosion Classification Scoring Table) was developed which included estimates of bank erodibility that included length, height, slope, soil material, vegetation density, and erosion indicators. The predominant land use adjacent to the stream was also recorded.

Table 4 - Riverbank Erosion Classification Scoring Table

Erosion Factor	Factor Description and (Associated Value)						Score Range
Riverbank Material	Bedrock (1)	Gravel (2)	Clay (3)	Sand (4)			1 - 4
Bank Height	Low <5' (1)	Med.5-10' (2)	High 10-20' (4)	Very High >20 (8)			1 - 8
Bank Slope	Flat >4:1* (1)	Med. 4-2:1 (2)	Steep <2:1 (6)	Vert./Undercut (8)			1 - 8
Degree of Vegetation	Heavy (1)	Moderate (2)	Sparse (4)	None (7)			1 - 7
# Erosion Indicators[1]	One (1)	Two (2)	Three (3)	Four (4)	Five (5)	Etc. (#)	1 - #
Bank Length	0-99 ft (1)	100-199 (2)	200-299 (3)	300-399 (4)	400-499 (5)	500+ (6)	1 - 6
						Total Score Range	6 - 38+

* Slope estimated as 4:1 = 4 units horizontal to 1 unit vertical

[1] Erosion indicators include observed active erosion, seeps and springs, superficial slides, mass wasting, undercut toe.

These factors were assigned a numerical value indicating erosion severity. In the office, these values were totaled for each eroding reach or site and assigned an erosion severity level of low, moderate, high, or very high.

Field Technique

The reach of the river chosen to float was the section from Randolph to Bethel. Field data were collected as we floated downstream. A small boat with motor was used to provide a relatively stable platform that could easily hold a position for taking photographs, recording streambank observations and obtaining Global Positioning System (GPS) location information. If normal water levels had been encountered, the process would have been much easier. Unfortunately, at the time of the study, the river was at a very low stage. The flood of 1998 created large amounts of large woody debris in the channel that made navigation somewhat difficult. Certainly, this boat method would work more easily on a larger river.

The float trip was chosen to save time while providing continuous observation of a significant portion of the Third Branch riverbanks. It also allowed access for detailed in-stream and bank measurements that would not have been possible in the time available from road or foot access. There may also be opportunities to gather data by acquiring high-resolution satellite photographs of the river. Although we did not use that method, it would be worthwhile exploring at a future date.

Three electronic digital devices were used to improve efficiency and accuracy of the data collection process (See Figure 7 - Data Recording Equipment). An Apple Newton™ handheld computer equipped with Fieldworker™ software was used to log all information. A template was developed with pick lists to reduce the quantity of written notes and facilitate the easy acquisition of data. The Apple Newton™ was cabled to a Rockwell PLGR GPS unit. At each data acquisition point the GPS provided an accurate position that the software attached to the data record being input. The GPS is accurate to within 30 feet horizontal location.

A digital camera with voice recording capabilities provided a visual and audio record of each data collection location. The audio file associated with each photograph was very useful in organizing and checking site descriptions logged on the Newton™.

Each night, the data was downloaded to a laptop computer to avoid loss during the next day's fieldwork. At the home office, data was downloaded to a spreadsheet where additional data analysis was performed.

Figure 7 - Data Recording Equipment

Note: Depiction of equipment used by NRCS implies no approval or endorsement of the products or manufacturers to the exclusion of others that may also be suitable.

<u>Lessons Learned</u>

1. Data gathering while afloat did save time but can not replace the need to get out of the boat for detailed measurements at many erosion sites.
2. When floating a river for data collection, allow significantly more time than what is required to simply canoe the river.
3. Provide for normal and backup power requirements for all electronic equipment.
4. Secure all electronic equipment in waterproof bags if possible.
5. Obtain the services of a local person familiar with landmarks, landowners and land use in the watershed area.
6. Make use of the voice recording ability of a digital camera while taking photographs.
7. Always download data in the evening.
8. Use a range finder to estimate streambank lengths, etc.
9. Employ a multi-disciplinary team to maximize the benefits of field data gathering.

RESULTS

Stream Classification

Hydraulic Geometry Curves

It is useful to measure bankfull widths and depths at gage sites in order to develop a regional hydraulic geometry curve relating width, depth, and cross-sectional area to drainage area. A regional curve can be used to corroborate bankfull measurements at ungaged sites, and it helps untrained staff to determine if a problem site is stable or not. If a channel is much deeper or wider than predicted by the regional curve, that stream may be unstable.

Dunne and Leopold's (1978) regional curve for the Eastern United States was examined to see if the bankfull dimensions of Ayers Brook near the stream gage could be predicted. For a 30.5 square mile drainage area, bankfull width from the curve was 50 feet and mean depth was 4.0 feet. These dimensions were similar to the actual measurements of 48 and 3.7 feet for the cross section at the cableway so, again, the team may have selected the appropriate bankfull surface at the Ayers Brook site. The Eastern United States curve data is primarily based on Maryland streams, so it probably should not be used for predicting bankfull channel dimensions in Vermont streams.

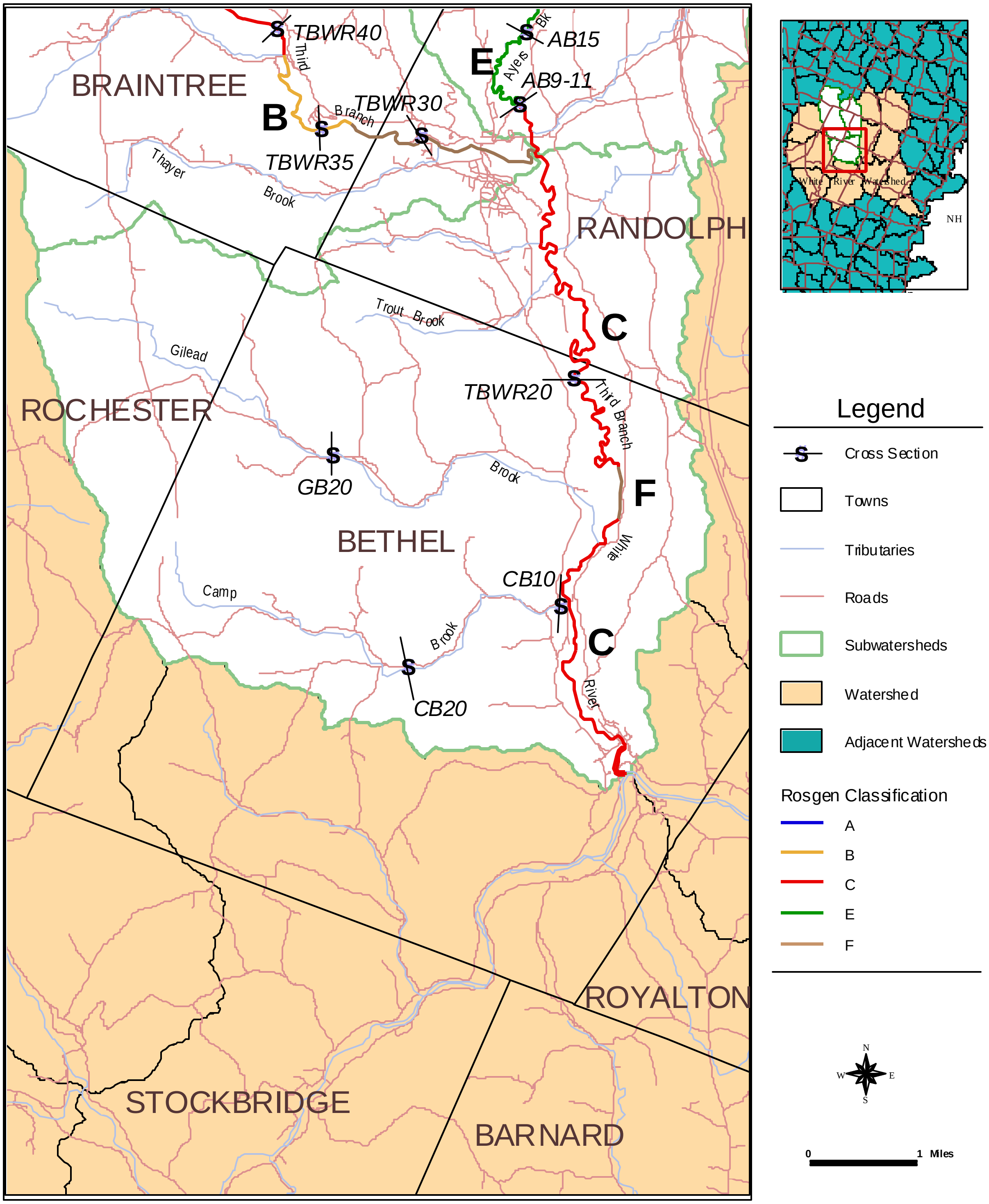
The team was unable to match the elevation of the bankfull surface to a gage height at the gage due to problems interpreting the elevations of the reference points at the gage relative to the zero datum on the expanded rating table. It is useful to determine the frequency of the flow event that fills the bankfull channel at various stream gage sites in a study area. The bankfull frequency should be in the 1-3-year return interval if the correct bankfull surface was selected. The bankfull flow frequency based on stream gage sites can be extrapolated to ungaged streams with calculated flow frequency distributions.

Manning's Equation was used with the Q = VA relationship (discharge = velocity x cross-sectional area) to estimate the discharge that filled the bankfull cross section measured at the stream gage. For a cross-sectional area of 180 square feet and a velocity of 2.5 feet per second, the bankfull discharge was 450 cubic feet per second (cfs) or a 1.15-year event. This indicates that the team's selection of the bankfull surface may be accurate since the bankfull discharge did fall within the 1-3-year return interval. Once the correct datum is determined for the Ayers Brook gage, the actual bankfull discharge and frequency can be determined.

Third Branch Downstream of Randolph

The Third Branch was observed at three different locations in a 4-mile reach downstream of Randolph. A cross section survey was performed at one of these locations (See Figure 8 - Third Branch Cross Sections Downstream of Randolph). Cross sections done on Camp and Gilead Brooks are also shown on this figure. The remaining 5.5 miles of the Third Branch were not observed during the field work. The river appears to be a degraded C4 stream type in Stage III of the Channel Evolution Model (CEM). The active bank erosion in this reach may be due to the river continuing

Figure 8 - Third Branch Cross Sections Downstream of Randolph



to adjust its cross-section dimensions and plan form since gravel mining was curtailed in 1986. However, the riparian corridor vegetation is also in poor condition so the banks have little erosion resistance. The accelerated bank erosion may be due to one or both of these two probable causes. The Vermont Stream Alteration Engineer did comment that the banks in this reach appear to be eroding at a reduced rate from 10 years ago when the gravel mining was still occurring.

There are high, 8 feet or greater, eroding banks at a number of locations in the Third Branch reach downstream of Randolph. These high banks occur as the river migrates across the valley floor and encounters the valley walls consisting of glacial terraces. It does not appear that the high banks are due to downcutting in the Third Branch. However, the presence of the high banks and the accelerated rate of bank erosion indicate this reach is probably producing the greatest amount of sediment to the White River compared to all the reaches observed in the field the week of June 15, 1998. This reach was turbid the week of June 15, following a large rainfall event.

Third Branch Upstream of Randolph

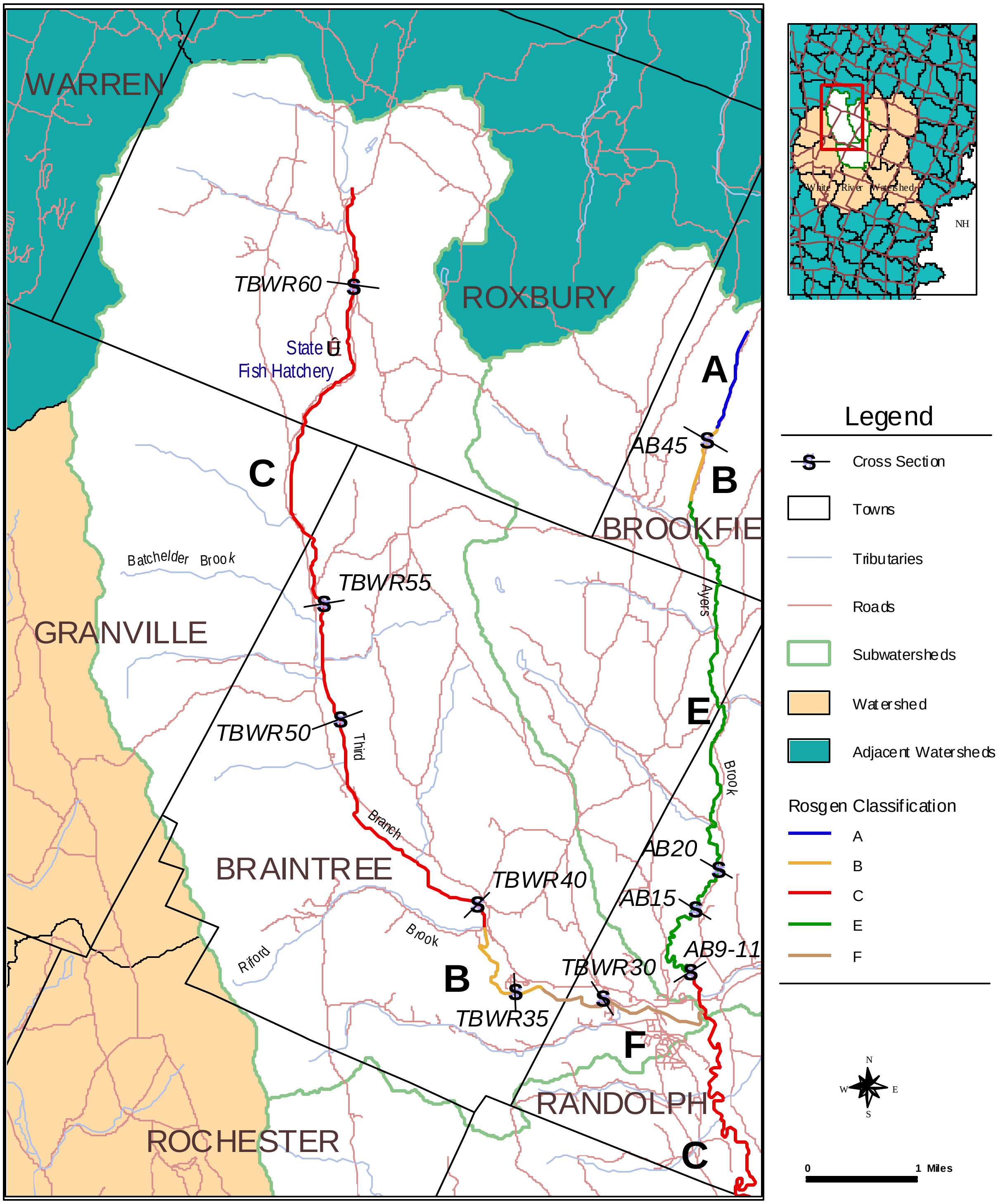
The Third Branch upstream of Randolph was observed, and cross section surveys performed, at six different locations (See Figure 9 - Third Branch Cross Sections Upstream of Randolph). The river appears to be a C3/C4 river in fairly stable condition except where the cross section was modified by pushing gravel and cobbles out of the bed of the river and up onto the banks and the floodplain after the floods of 1973 and 1976. Where the gravel and cobble “windrows” became stabilized by woody vegetation, the river appears to take on the characteristics of a B3/B4 stream type (moderately confined) as seen at the commercial campground just upstream of Randolph. The gravel windrows may have extended from the town park in Randolph to just below the confluence of Riford Brook and the Third Branch. The river just upstream of the park and upstream of Riford Brook appears to be a C3/C4. The river adjacent to the gravel pit south of the river downstream from Riford Brook appeared to be similar to the river at the campground (B3/B4).

The river between Riford Brook and Batchelder Brook, the next location observed, is a C3/C4. Just upstream of Batchelder Brook, the river may be more similar to a B or F stream type due to the encroachment of the highway and the railroad in that narrow valley floor reach.

The last location observed on the Third Branch was just below the State Fish Hatchery near Roxbury. The river was classified as a C3/C4, but it appeared somewhat degraded. The active bank erosion appeared to be due to the poor condition of the riparian corridor vegetation as opposed to a channel adjustment process. The banks are low in height, so the stage of channel evolution for this reach was either Stage I or Stage III.

The river was not observed between the railroad crossing above Batchelder Creek and the last point surveyed. It appeared the river had been moved up against one side of the valley floor or the other throughout this reach to facilitate access to the valley floor for farming and to keep the river away from the road and railroad. Linear wetlands, some with beaver dams, were evidence of old channel remnants prior to channel

Figure 9 - Third Branch Cross Sections Upstream of Randolph



realignment. It is assumed the river has evolved to a C3/C4 similar to the reaches observed upstream and downstream of this reach. However, the channel modifications may have resulted in disconnecting the river from its active floodplain. In those situations, the Third Branch may be an F or B stream type.

This reach of the Third Branch was flowing clear even though heavy rains and high runoff occurred the week we were in the field. This indicated that there was little streambank erosion occurring in the Third Branch or its tributaries above Randolph.

Ayers Brook

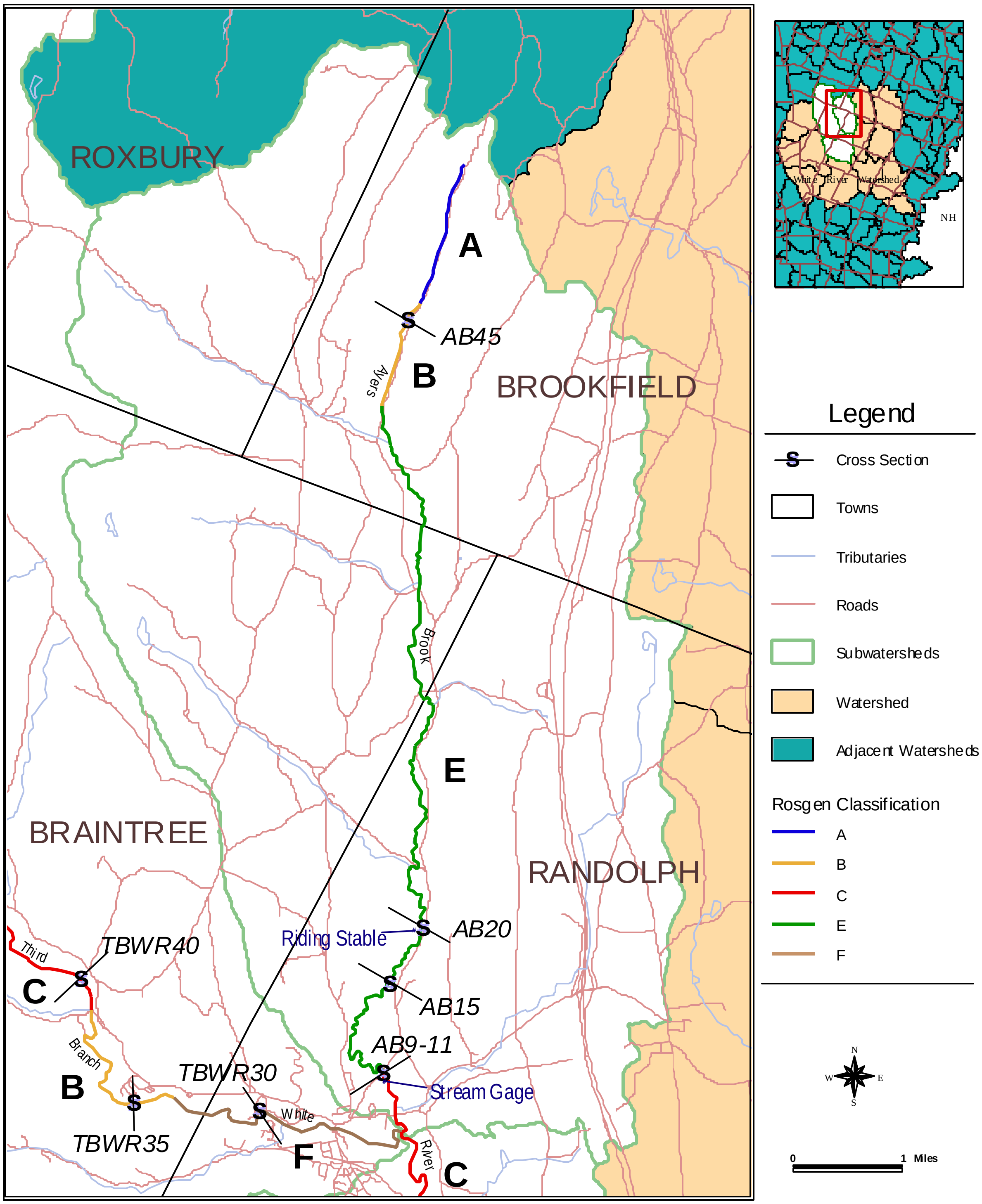
Ayers Brook was examined at five different locations, and six cross sections were surveyed (See Figure 10 - Ayers Brook Cross Sections). The channel is an F4/5 (Stage III or early Stage IV) in the lower one mile upstream of the stream gage in Randolph. One of the two cross sections measured in this reach was classified as a B4/5, but most of the channel appeared to be an F. The channel did not appear to be downcutting, but the high banks in this reach were actively sloughing. The high banks appeared to be due to the stream migrating into glacial lake sediments which formed a high terrace close to the creek. A prior heavy rainfall event produced a river that was turbid at all of the sites examined except for the steeper Class A and B reaches near the watershed divide. Bank erosion appeared to be the primary source of sediment in Ayers Brook. High-bank erosion was due to the stream migrating into the glacial terrace and the low-bank erosion appeared to be due to the poor condition of riparian corridor vegetation. The channel appeared to be vertically stable but widening due to the accelerated bank erosion.

The active floodplain adjacent to the stream became wider further upstream. The channel became unconfined at about one mile upstream of the gage, and it was classified as an E4/E5 stream with a W/D ratio of 10 (39.7 feet/ 3.9 feet). An E stream type in good condition usually has a much lower W/D ratio than 12. It appears that the poor condition of the riparian vegetation was allowing accelerated streambank erosion resulting in a wider stream. The stream width in this reach was similar to the 40-foot width near the gage. Even though the stream was classified as an E, it is probably an E degrading into a C.

Farther upstream, approximately 3 miles above the stream gage, at the riding stable, the active floodplain became wider and the stream was narrower. Typically, floodplain widths and stream widths become narrower in an upstream direction as drainage area decreases. However, the drainage area had not decreased significantly at the riding stable compared to the gage site. The floodplain width had increased due to the decreased extent of the glacial lake sediments upstream of the mouth of Ayers Brook. The stream appeared to be a more stable E. It was classified as an E4/5 with a W/D ratio of 7 (29 feet / 4.4 feet). The decreased rate of bank erosion at this site led the group to place it in Stage I/V of channel evolution as opposed to Stage III in other reaches.

The channel was observed at a point about 5 miles upstream of the gage, but no measurements were taken. There were no glacial lake sediments or other terraces in this reach, and the active floodplain was almost a half-mile wide. Active bank erosion

Figure 10 - Ayers Brook Cross Sections



was occurring in this reach. The erosion appeared to be due to the poor condition of the riparian corridor vegetation as opposed to a channel adjustment process.

The next upstream cross section was on a reach of stream that had an active floodplain between it and the road. This unconfined stream had a W/D ratio of 13 and a slope of about 3%. This reach was classified as a Cb3/b4; a steep C stream type. It appears to be stable and may be a transition between the steeper A and B types upstream and the E channel further downstream.

Data Summary

The measured and computed stream parameters and resulting Rosgen Stream Classification (Stream Type) for each field survey location are summarized below in three tables. The first is for the Third Branch (See Table 5 - Stream Classification Data Summary - Third Branch) followed by Ayers Brook (See Table 6 - Stream Classification Data Summary - Ayers Brook) and the smaller tributaries, Camp & Gilead Brooks (See Table 7 - Stream Classification Data Summary - Camp & Gilead Brooks).

Erosion and Sedimentation Survey

Data Accuracy

Data collected for this reconnaissance study is intended to show the relative importance of erosion types as part of the entire erosion picture. The data is not intended for purposes beyond that for which they are presented here. Further detailed work on streambank erosion rates, meander pattern history, and sediment transport would help to refine and extend the usefulness of the data.

The GPS unit used was accurate to within 30 feet for horizontal location. Streambank lengths were estimated and assumed accurate to within 10 percent. Streambank recession rates were estimated from aerial photographs and observation in the field.

Riverbank lengths were measured from aerial photographs, GIS, and topographic maps. GIS lengths were utilized for the erosion calculations.

Sediment Budget for Third Branch Watershed

A sediment budget is used to calculate the amount of sediment produced in a watershed. The quantity of sediment produced from all erosion sources is estimated using various procedures. Depending on the source of erosion, this quantity is multiplied by a factor known as a delivery ratio that further refines the estimate of how much of the eroded soil actually enters a stream. For instance, a smaller percentage of soil eroding from agricultural fields will be delivered to a stream than erosion taking place directly on the streambanks.

Table 5 - Stream Classification Data Summary - Third Branch

Parameters	Location (Cross Section) Measured / (Estimated) Data						
	TBWR20	TBWR30	TBWR35	TBWR40	TBWR50	TBWR55	TBWR60
Bankfull WIDTH (W_{bkf}) ______________ Ft.	114.0	97.3	61.5	66.0	68.4	62.0	36.0
Mean DEPTH (d_{bkf}) ________________ Ft.	4.0	3.5	2.9	3.8	1.9	2.2	1.7
Bankfull X-Sect. AREA (A_{bkf}) ______ Sq.Ft.	458.6	344.3	178.7	252.4	133.1	135.4	60.6
Width / Depth RATIO (W_{bkf} / d_{bkf}) _____	28.5	27.8	21.2	17.4	36.0	28.2	21.2
Maximum DEPTH (d_{mbkf}) ____________ Ft.	7.1	6.3	3.6	4.7	3.4	4.0	3.1
WIDTH of Flood-Prone Area (W_{fpa}) ____ Ft.	(300.0)	103.0	110.0	(400.0)	558.0	701.0	89.0
Entrenchment Ratio (ER) ___________	2.6	1.1	1.8	6.1	8.2	11.3	2.5
Channel Materials D50 ____________ mm.	(Gravel)	30.0	(Cobble)	85.0	16.0	20.0	(Gravl/Cobl)
Water Surface SLOPE (S) _________ Ft./Ft.	(0.0010)	(0.0100)	(0.0010)	(0.0010)	0.0036	0.0039	0.0059
Channel SINUOSITY (K) ___________	1.77	1.13	1.13	1.13	1.06	1.06	1.11
ROSGEN STREAM TYPE	C4	F4	B3	C4	C4	C4	C3/C4

Note: Shaded rows are : Primary Stream Classification Parameters

Table 6 - Stream Classification Data Summary - Ayers Brook

Parameters	Location (Cross Section) Measured / (Estimated) Data						
	AB9	AB10	AB11	AB15	AB20	AB40	AB45
Bankfull WIDTH (W_{bkf}) ______________ Ft.	29.6	35.5	47.6	39.7	29.0		12.0
Mean DEPTH (d_{bkf}) _________________ Ft.	2.9	3.6	3.6	3.9	4.4		1.0
Bankfull X-Sect. AREA (A_{bkf}) ______ Sq.Ft.	84.6	127.4	172.8	153.9	129.0		11.9
Width / Depth RATIO (W_{bkf} / d_{bkf}) _____	10.2	9.9	13.2	10.2	6.6		12.0
Maximum DEPTH (d_{mbkf}) ____________ Ft.	4.3	4.8	4.9	5.7	5.5		1.5
WIDTH of Flood-Prone Area (W_{fpa}) ____ Ft.	(50.0)	58.5	63.0	145.0	200.0		50.0
Entrenchment Ratio (ER) ___________	1.7	1.6	1.3	3.7	6.9		4.2
Channel Materials D50 ____________ mm.	(Sand/Gravl)	(Sand/Gravl)	(Sand/Gravl)	(Sand/Gravl)	(Sand/Gravl)		(Sand/Gravl)
Water Surface SLOPE (S) _________ Ft./Ft.	(0.0010)	0.0007	0.0007	0.0014	0.0016		0.0290
Channel SINUOSITY (K) ___________	1.53	1.53	1.53	1.23	1.23		1.05
ROSGEN STREAM TYPE	B4/B5	B4/B5	F4/F5	E4/E5	E4/E5		C4

Note: Shaded rows are : Primary Stream Classification Parameters

Table 7 - Stream Classification Data Summary - Camp & Gilead Brooks

Parameters	Location (Cross Section) Measured / (Estimated) Data						
	CB10	CB20	GB20				
Bankfull WIDTH (W_{bkf}) ______________ Ft.	34.0	30.2	32.1				
Mean DEPTH (d_{bkf}) _________________ Ft.	1.5	1.6	1.6				
Bankfull X-Sect. AREA (A_{bkf}) ______ Sq.Ft.	49.7	47.5	51.7				
Width / Depth RATIO (W_{bkf} / d_{bkf}) _____	22.7	18.9	20.1				
Maximum DEPTH (d_{mbkf}) ____________ Ft.	2.0	2.5	2.5				
WIDTH of Flood-Prone Area (W_{fpa}) ____ Ft.	42.0	104.0	44.0				
Entrenchment Ratio (ER) ___________	1.2	3.4	1.4				
Channel Materials D50 ____________ mm.	(Gravl/Cobl)	(Cobble)	(Gravl/Cobl)				
Water Surface SLOPE (S) _________ Ft./Ft.	0.0140	0.0340	0.0198				
Channel SINUOSITY (K) ___________	1.40	1.10	1.05				
ROSGEN STREAM TYPE	F3/F4	C3b	B3/4 F3/4				

Note: Shaded rows are : Primary Stream Classification Parameters

The Third Branch Watershed sediment budget computations included three primary erosion sources: 1) watershed sheet and rill erosion, 2) dirt road surface erosion, and 3) streambank erosion. An appropriate erosion rate in Tons/Acre/Year was applied to each of four land use types including forest, hayland, cropland, and non-eroding land. In the case of the 41 miles of dirt roads in the watershed, a determination was made to apply two different erosion rates depending on the type and condition of the roads. Streambank recession rates were based on factors associated with various reaches of stream in the watershed. The four reaches selected were; 1) Ayers Brook watershed, 2) Third Branch watershed upstream of Randolph, 3) Third Branch tributaries upstream of Randolph, and 4) Third Branch watershed downstream of Randolph.

Streambank erosion rates were estimated in the field by trained observers based on their knowledge of the Third Branch and other watersheds. Aerial photos and historic topographic maps were also consulted. Field measurements were compared to aerial photographs at key locations to verify some of the recession rate estimates. Factors used in computations for streambank erosion include predominant soil types and associated weights per cubic foot, observed bank heights in the various reaches, and observed severity of actively eroding streambanks. The Streambank Erosion Inventory Site Location Maps (See Figures A1-A12 in Appendix A) show the location and severity of erosion in the Third Branch. More detailed information regarding the various erosion sites observed can be found in the basic data files for this study that are maintained in the NRCS Field Office located in Berlin, Vermont.

The overall story of erosion in the Third Branch White River Watershed is summarized numerically in the table of sediment budget data for Ayers Brook and the Third Branch (See Table 8 - Sediment Budget Data Summary). From this information one can see that the streambanks contribute 72 percent of all sediment reaching streams in the watershed. In the lower reaches of the Third Branch downstream of Randolph, the contribution from the streambanks is even higher at 80 percent.

The geology of the Third Branch downstream of Randolph is typified by glacial-lake soils. Overall, the glacial-lake deposits are finer-grained silts and sands underlain by coarser sands and gravels. These weak-strength deposits are easily eroded and subject to failure on high steep slopes. This reach of the river is also tortuously meandering. Topographic maps and aerial photographs show that throughout the twentieth century this river has meandered across its floodplain making new channels and abandoning old. Active erosion is evident throughout the reach. The reason this section was chosen to float and evaluate the erosion more closely was due to the fact that it was known to be the most highly eroding section of the river.

Table 8 - Sediment Budget Data Summary

Erosion Type	Sediment Delivered (Tons/Year)	Percent of: Subwatershed	Total
AYERS BROOK			
Sheet & Rill	1,350	27	9
Dirt Road Surface	340	7	2
Streambank	3,264	66	22
Sub-Total	4,954	100	33
THIRD BRANCH - U/S OF RANDOLPH (Excluding Ayers Brook)			
Sheet & Rill	1,076	25	7
Dirt Road Surface	371	9	3
Streambank	2,852	66	20
Sub-Total	4,299	100	30
THIRD BRANCH - D/S OF RANDOLPH			
Sheet & Rill	780	15	5
Dirt Road Surface	269	5	2
Streambank	4,310	80	30
Sub-Total	5,359	100	37
TOTAL	14,612		100

Note: For additional sediment budget details see Appendix C.

Third Branch Streambank Erosion

Because streambanks are the major contributor of sediment in the watershed, particularly in the lower reaches, the primary focus of the erosion survey, both with historical and field data gathering, was on the streambanks.

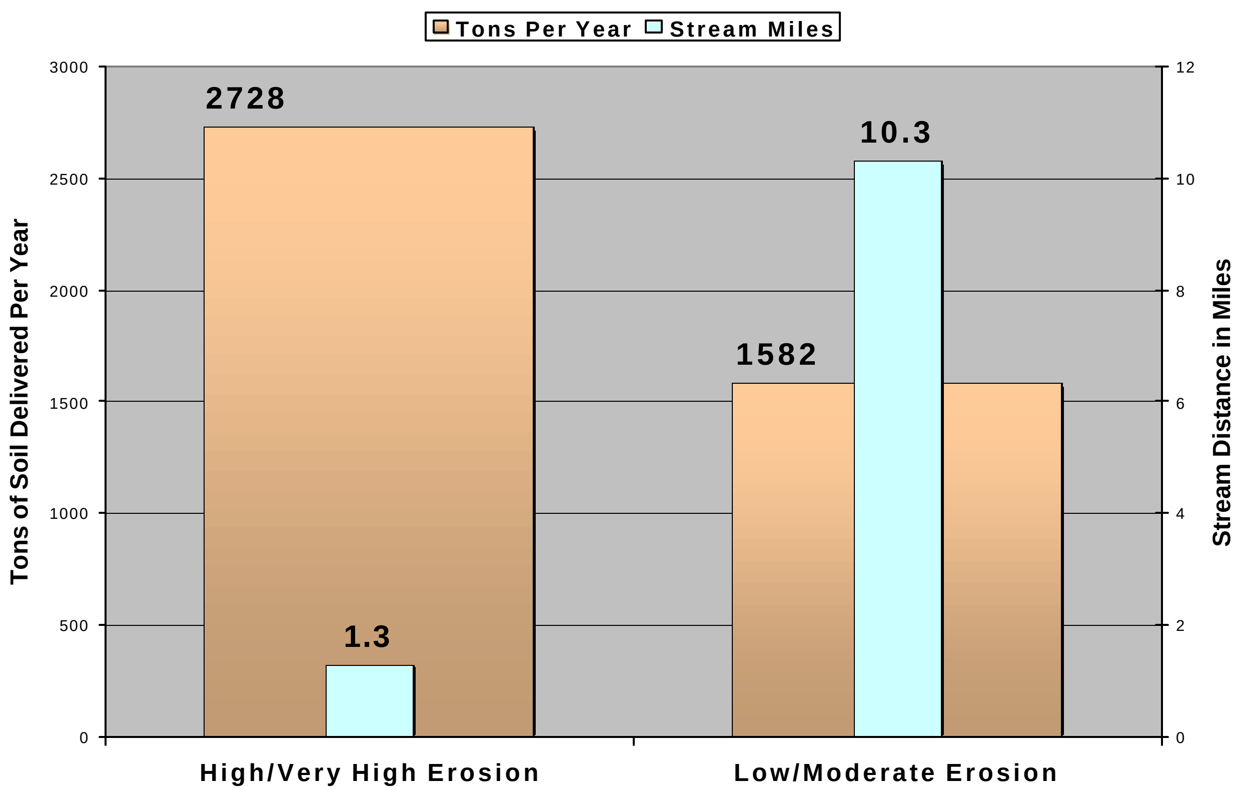
The 1976 photographs (Cook 1976) convey the message that the White River has been an active river aggressively eroding its floodplain. This phenomenon is not new nor is it about to stop. Woody debris in the 1976 photographs is very similar to debris seen in 1999. The watershed has not been heavily urbanized which would increase runoff. The watershed experiences large floods which create new channels and abandon others throughout the floodplain.

Two notable meander cutoffs have occurred in recent times in the Third Branch. Aerial photographs show a contorted meander just near the Bethel-Randolph town boundary that appears to have been cut off near the time of the 1976 photograph. Another meander cutoff was created during the 1998 flood. This meander cutoff located near the golf course is shown in photograph Figure A3 in Appendix A. These meander cutoffs are indicative of a river channel undergoing change. When a meander cutoff occurs, the channel length is shortened, producing an increase in channel slope and thereby increasing its sediment load carrying capacity.

Increased erosion can also be caused by removal of gravel bedload from the river system. When a reach of stream has its bedload removed, the water flowing in it becomes "hungry". Hungry water has more energy because it is no longer carrying the sediment that has been removed and therefore attacks the streambanks or bed to replace the bedload until a new equilibrium is reached.

Even though erosion rates are difficult to estimate without long term monitoring, the historical rates of erosion in this river appear to be quite high. By taking some measurements, talking to residents, and applying experience from other watersheds, erosion estimates of the correct magnitude can be determined. Long and high eroding slopes and slope failures exist in several locations. These are major mass movements that occur infrequently but can take many feet of streambank in one slide. Averaged over a number of years, this results in a significant recession rate of the streambank.

Figure 11 - Tons of Soil Delivered and Stream Distance by Category



The computations bear out visual indicators found during the field survey. For instance, the sediment delivered from a 1.3 mile stretch of river with severely eroding banks is 2728 tons/yr. That value exceeds the total eroded from the remaining 10.3 miles of stream where a more normal rate of erosion was occurring (See Figure 8 - Tons of Soil Delivered and Stream Distance by Erosion Category).

This illustrates the significance of a few highly eroding steep locations where unstable soils are responsible for large amounts of sediment delivered. At one of these locations the water was discolored from the contribution of silt from the slope. This discoloration could be seen in a predominantly clear water condition that was present in the remainder of the river system that day. Slopes eroding in severe fashion such as this are very difficult to address through cost-effective erosion control methods.

Because the field work was done following a major flood, much of the streambank vegetation that may have existed prior to the flood was gone with a resulting increase in raw eroding banks during our survey. Floods of this magnitude are relatively rare, so it is reasonable to assume that vegetation will reestablish on some of the eroding banks and provide increased stability and decreased erosion rates. There are many areas, however, that erosion is a chronic situation or the damage caused by the flood cannot be overcome by natural means.

CONCLUSIONS

1. The assessment team concluded that the Rosgen stream classification is a useful watershed assessment tool. Schumm's Channel Evolution Model does not provide all of the detail that the Rosgen system includes, so it is probably not appropriate to use as a stand-alone assessment tool. However, Schumm's model may be an appropriate public education tool since it is a much easier system to learn and comprehend. It also provides a perspective of what has already occurred and what can be expected in the future whereas the Rosgen system deals with what is currently observed. These two classification systems compliment each other for the purpose of gaining a better understanding of the geomorphic processes at work in a dynamic river system.

2. The A and B stream types occurring in the headwaters and side valleys along the Third Branch and Ayers Brook are probably stable stream types for those landscape positions (Stage II).

3. The C and E stream types in the valley floors also appear to be stable (Stage I or V) except where the riparian corridor vegetation is absent or in poor condition (Stage I, III, or V). It appears that Width to Depth ratios that exceed 25 for C streams and 7 for E streams may indicate some lateral instability. Some of the accelerated bank erosion on the Third Branch downstream of Randolph may be due to the river adjusting to past gravel mining activities. However, most of the accelerated bank erosion and widening in these streams appears to be due to the lack of, or the poor condition of, the riparian corridor vegetation as opposed to any inherent channel instability.

4. B and F stream types that occur in valley floor reaches usually appear to be the result of stream disturbance (realigned, confined by flood "restoration" activities, or confined by highway or railroad fills) (Stage II, III, or IV). The confinement problems are most extreme where the valley floor is most narrow. The B stream types may or may not be stable, but the F types are highly unstable. B stream types with armored banks and bed structures that dissipate energy (step-pools, constant riffle, or constant rapids) appear to be stable (Stage II). The unstable B and F streams typically have less erosion resistant banks and exhibit accelerated bank erosion (widening) typical of late Stage II, throughout all of Stage III, and early in Stage IV of channel evolution. Some unstable B and F streams occur in the lower reaches of Ayers Brook and the Third Branch downstream of Randolph. These reaches are confined by glacial lake sediments, which form high banks on each side of the stream. The high banks are eroding through mass wasting (Stage III).

5. There have been numerous historical changes in the White River Watershed that has impacted streams. Based on examining some of the gage records, annual peak flows today are similar to peak flows forty years ago. The current flow regime that produces channel-forming, bankfull discharges has been in operation for a long period, and streams do not appear to be adjusting to any historic hydrologic changes. There does not appear to be any major channel adjustments occurring today due to historic changes in sediment loads. The bank erosion in the lower reaches of the Third Branch may be due, in part, to the historic gravel mining that was curtailed in 1986. It is not clear if this reach has reestablished its pool/riffle

spacing or if it has recruited enough gravel to rebuild all of its point bars to reduce stress on the outside banks of meanders during high flows.

6. Each major stream reach in the watershed, Third Branch downstream of Randolph, Third Branch upstream of Randolph, and Ayers Brook, is contributing similar amounts of sediment (37-, 30-, and 33-percent) with the vast majority coming from eroding streambanks (72%). Many high eroding banks occur where the stream flows through glacial lake sediments or where it has migrated across the valley floor into higher terraces or into the valley wall itself. The lack of woody vegetation typically occurs where the valley floor is cropped.

7. One of the major challenges for reducing excessive streambank erosion is finding a cost-effective method to stabilize or slow down the erosion from long sloping eroding banks. These raw banks are contributing massive amounts of sediment to the system. There may be innovative ways to control the sediment washing off the slopes.

8. A change in public attitudes towards gravel mining, towards buffers between streams and other land uses, and towards floodplain management in general appears to be a necessary ingredient to accomplish the watershed restoration goals of the White River Watershed Partnership.

9. Channel and floodplain encroachments associated with residential and commercial development as well as changes in watershed hydrology that result from increased road networks, ditches and channelized stormwater runoff are examples of negative effects of urbanization. As the population of the White River watershed grows, these effects can be expected to threaten channel stability unless careful land use planning is in place to provide protection.

RECOMMENDATIONS

1. Stream classification should continue in critical portions of the White River Watershed using both the Rosgen and Schumm classification systems. The additional information will be valuable in defining and prioritizing future stream protection and restoration efforts.

2. The WRP should facilitate determination of ecoregions that are associated with the State of Vermont. All the rivers with stream gages in Vermont and in adjacent states within those ecoregions should be classified in order to develop ecoregion curves of bankfull discharge and bankfull channel dimensions versus drainage area. Such "Regional Curves" would help natural resource planners identify unstable streams. Planners could also compare bankfull measurements made in the field to those predicted by the curves to help them decide if they selected the appropriate bankfull surface in the field. Designers could also use the curves as a starting point for designing reconstructed or rehabilitated channels.

3. The WRP should obtain assistance from a sociologist and a public information specialist to help them define strategies for educating the public about watershed problems and opportunities and motivating the public to change current management activities within and outside of the stream corridor. In this case, educational efforts must include outreach to the farm constituency, environmental community and landowners, particularly along the river where damage occurs regularly.

4. The WRP should facilitate development of an aggressive riparian buffer program involving local, state and federal organizations. The program must provide information, education and economic incentives.

5. Reestablishment of a riparian corridor should take full account of the existing stream morphology to insure that lack of riparian vegetation is the primary cause of excessive lateral migration. If other factors are also effecting channel stability, revegetation efforts may be inappropriate.

6. The White River Partnership should maintain a full-time coordinator position to integrate efforts of the partnership, federal agencies, state agencies, municipal governments, non-governmental organizations, and private landowners.

7. The WRP should endeavor to prioritize its protection and restoration projects with the following factors in mind: 1) improving the most sensitive channel types (i.e. E's and C's) may provide the greatest environmental benefit, 2) a cost/benefit analysis is necessary to appropriately allocate resources, and 3) when possible, working from upstream to downstream will be more effective for improving instream habitat conditions.

8. The WRP should monitor erosion in "F" type stream reaches to determine the actual erosion rate. A decision can then be made to develop a treatment method or allow the stream to evolve into a stable form on its own.

9. The WRP should consider conducting Rosgen Level III monitoring in unstable Type C and E reaches to determine rates of evolution/change. This will involve use of erosion-monitoring pins installed in streambanks along with survey benchmarks to measure streambank recession rates. This would be a long-term study using volunteers for obtaining the measurements. These monitoring locations may also be useful in determining if treated sediment sources are reducing instream fine sediment.

10. Aerial and satellite photography of the watershed should be obtained to facilitate identification of features such as land use, vegetative cover, habitat, seasonal change, urban sprawl, etc.

11. Bioengineering structures should be constructed, monitored and evaluated at various locations in the watershed to determine suitability for use in natural channel design solutions for reaches of stream that are experiencing excessive erosion rates.

12. Graduate students should be enlisted from university and college departments to study the river system. Studies should include sedimentation and erosion, sediment transport, habitat evaluation and restoration, and land use studies, as well as opportunities for stream restoration.

13. The WRP should work with state agencies and municipal governments to evaluate current land use and zoning regulations with an eye toward their effect on floodplain development and the resulting impact on the streams in the watershed. A protection strategy can then be developed and adopted to reduce the rate and amount of runoff.

14. An update of the 100-year floodplain maps should be done based on the latest hydrology of the watershed.

15. The WRP should encourage local citizens, schools, fishing groups etc., to participate in stream enhancement related activities such as "Stream Cleanup Days" and "Adopt-a-Stream" programs.

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APPENDIX A (Photographs)

The following photographs (See Figures A1-A13) depict various Third Branch, Ayers Brook and other tributary stream locations of interest. The number in parentheses following the photo description is the Streambank Erosion Inventory Site Number that can be found on the maps in Appendix B.

Figure A1

Ayers Brook, Randolph - Riprap Bank Protection at Montague Golf Club (#64)

Figure A2
Third Branch, Braintree - Residential Riprap Site (#77)

Figure A3
Third Branch, Randolph - Meander Cutoff (#13)

Figure A4

Ayers Brook, Randolph - Streambank Erosion, Agricultural Area (#67)

Figure A5

Ayers Brook, Randolph - Erosion Near High School (#59)

Figure A6

Third Branch, Randolph - Flood/Erosion Destroys Park Footbridge (#70)

Figure A7

Third Branch, Randolph - Residential Property Erosion (#3)

Figure A8
Third Branch, Randolph - Sediment Deposits at Thayer Brook Tributary (#74)

Figure A9
Third Branch, Randolph - Gravel Layers Exposed (#25)

Figure A10
Third Branch, Randolph - Slope Failure (#26)

Figure A11
Third Branch, Bethel - High Bank Slope Failure (#42)

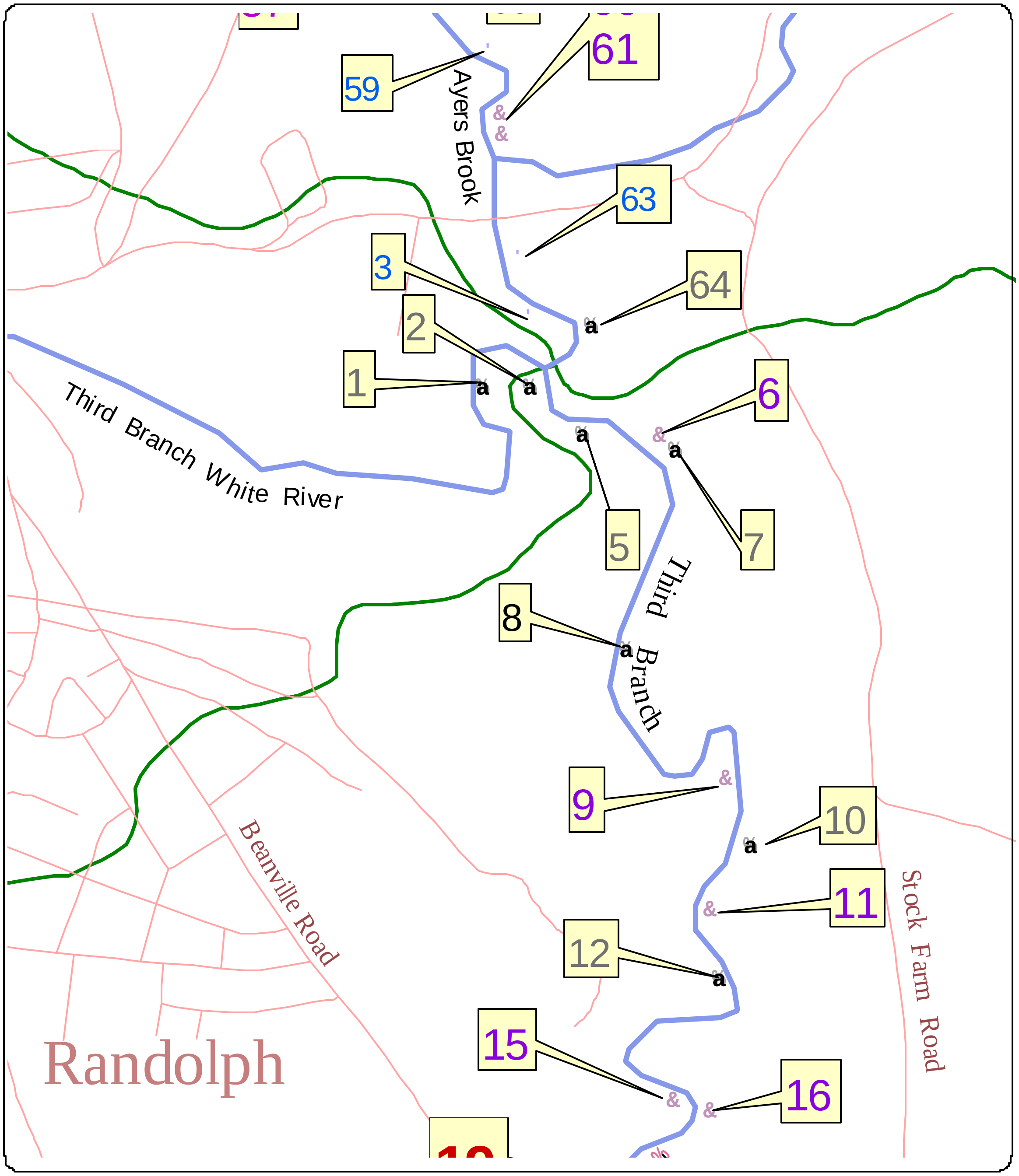
Figure A12
Third Branch, Bethel - Large Slope Erosion (#48)

Figure A13
Third Branch, Bethel - Large Slope Erosion, Agricultural Land(#48)

Appendix B (Streambank Erosion Inventory Site Location Maps)

These maps (See Figures B1-B12) provide a visual guide to the location of significant erosion sites in the Third Branch Watershed. They also show, by symbol type and color, the relative erosion severity range. Four ranges labeled low, moderate, high, and very high identify erosion severity.

Figure B1



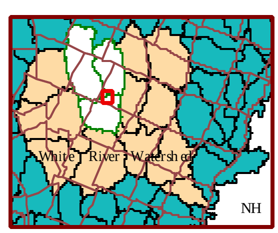
Legend

Streambank Erosion Severity

- a Rip-rap
- ' Low
- & Moderate
- % High
- $ Very High

- Streams
- Roads
- Towns
- Third Branch Subwatersheds
- White River Watershed
- Vermont Subwatersheds

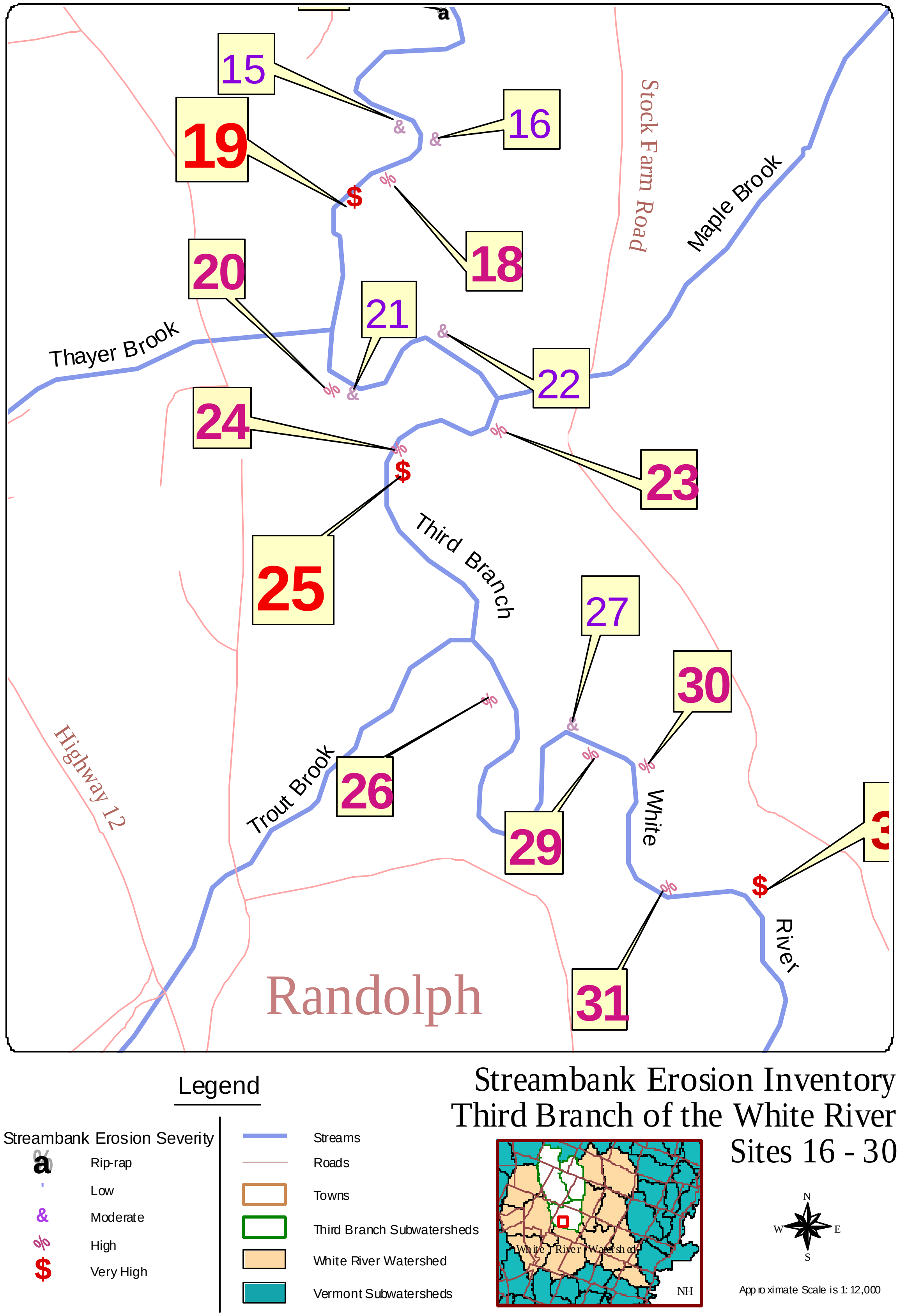
Streambank Erosion Inventory
Third Branch of the White River
Sites 1 - 15



N
W E
S

Approximate Scale is 1: 13,000

Figure B2



Streambank Erosion Inventory
Third Branch of the White River
Sites 16 - 30

Figure B3

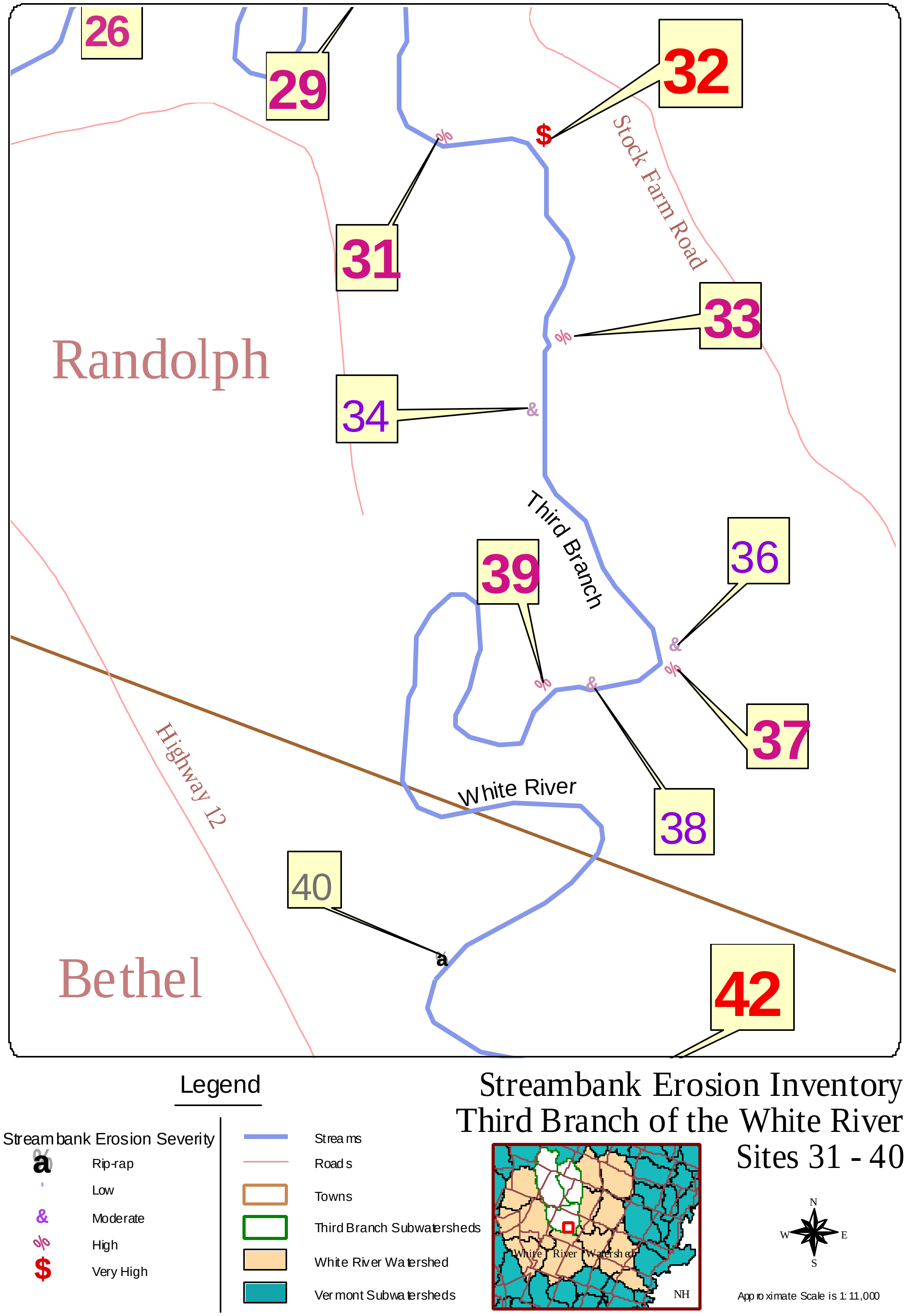

26
29
32
31
33
Randolph
34
Stock Farm Road
Third Branch
39
36
37
38
White River
Highway 12
40
Bethel
42
Legend
Streambank Erosion Severity
Rip-rap
Low
Moderate
High
Very High
Streams
Roads
Towns
Third Branch Subwatersheds
White River Watershed
Vermont Subwatersheds
Streambank Erosion Inventory
Third Branch of the White River
Sites 31 - 40
White River Watershed
NH
N
W
E
S
Approximate Scale is 1: 11,000

Figure B4

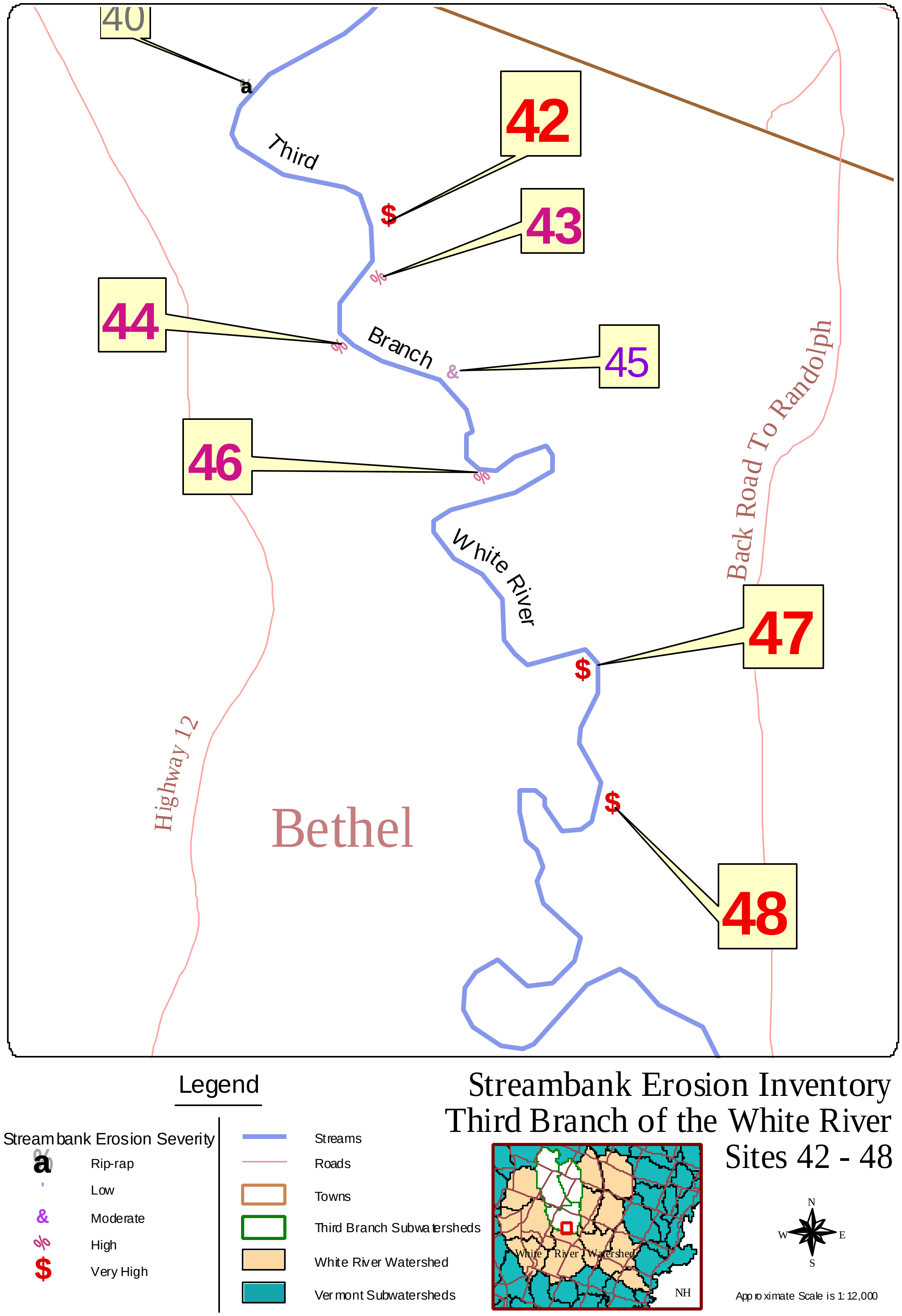

40
42
43
44
45
46
47
48
Third
Branch
White River
Back Road To Randolph
Highway 12
Bethel
Legend
Streambank Erosion Severity
Rip-rap
Low
Moderate
High
Very High
Streams
Roads
Towns
Third Branch Subwatersheds
White River Watershed
Vermont Subwatersheds
Streambank Erosion Inventory
Third Branch of the White River
Sites 42 - 48
White River Watershed
NH
N
W
E
S
Approximate Scale is 1: 12,000

Figure B5

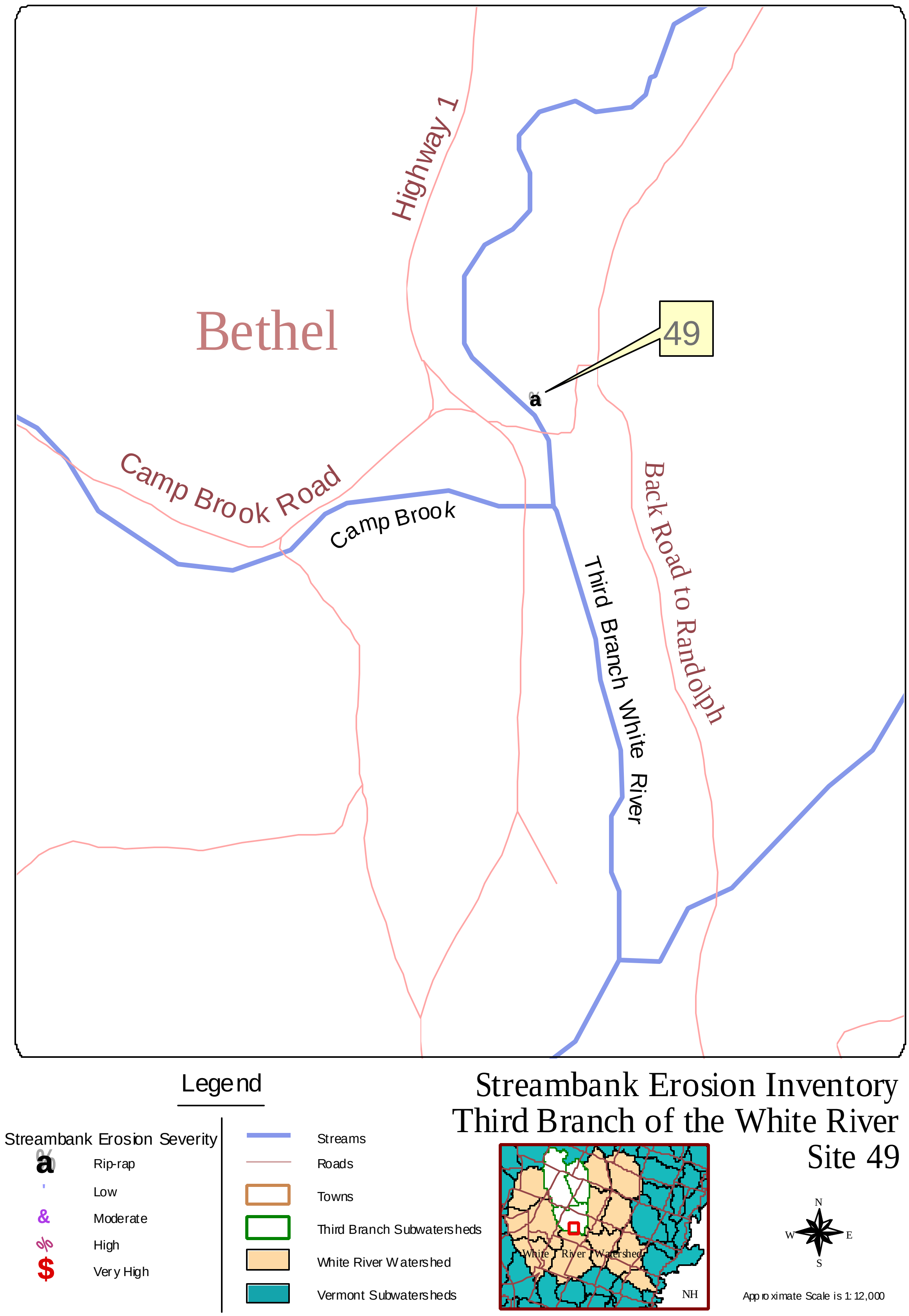
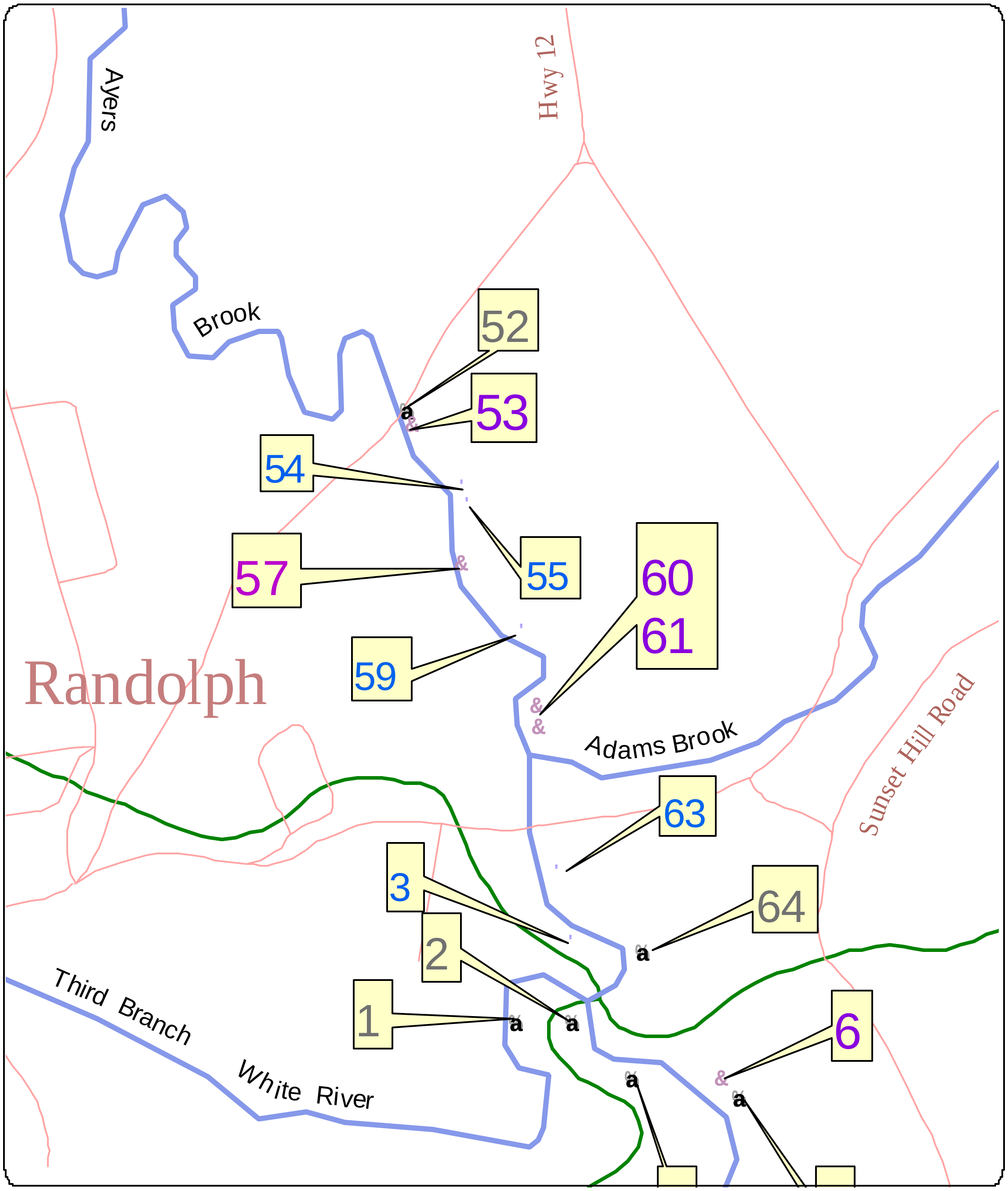

Highway 1
Bethel
49
Camp Brook Road
Camp Brook
Third Branch White River
Back Road to Randolph
Legend
Streambank Erosion Severity
Rip-rap
Low
Moderate
High
Very High
Streams
Roads
Towns
Third Branch Subwatersheds
White River Watershed
Vermont Subwatersheds
Streambank Erosion Inventory
Third Branch of the White River
Site 49
White River Watershed
NH
N
W
E
S
Approximate Scale is 1: 12,000

Figure B6

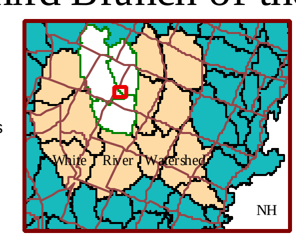


Legend

Streambank Erosion Severity
a Rip-rap
' Low
& Moderate
% High
$ Very High

Streams
Roads
Towns
Third Branch Subwatersheds
White River Watershed
Vermont Subwatersheds

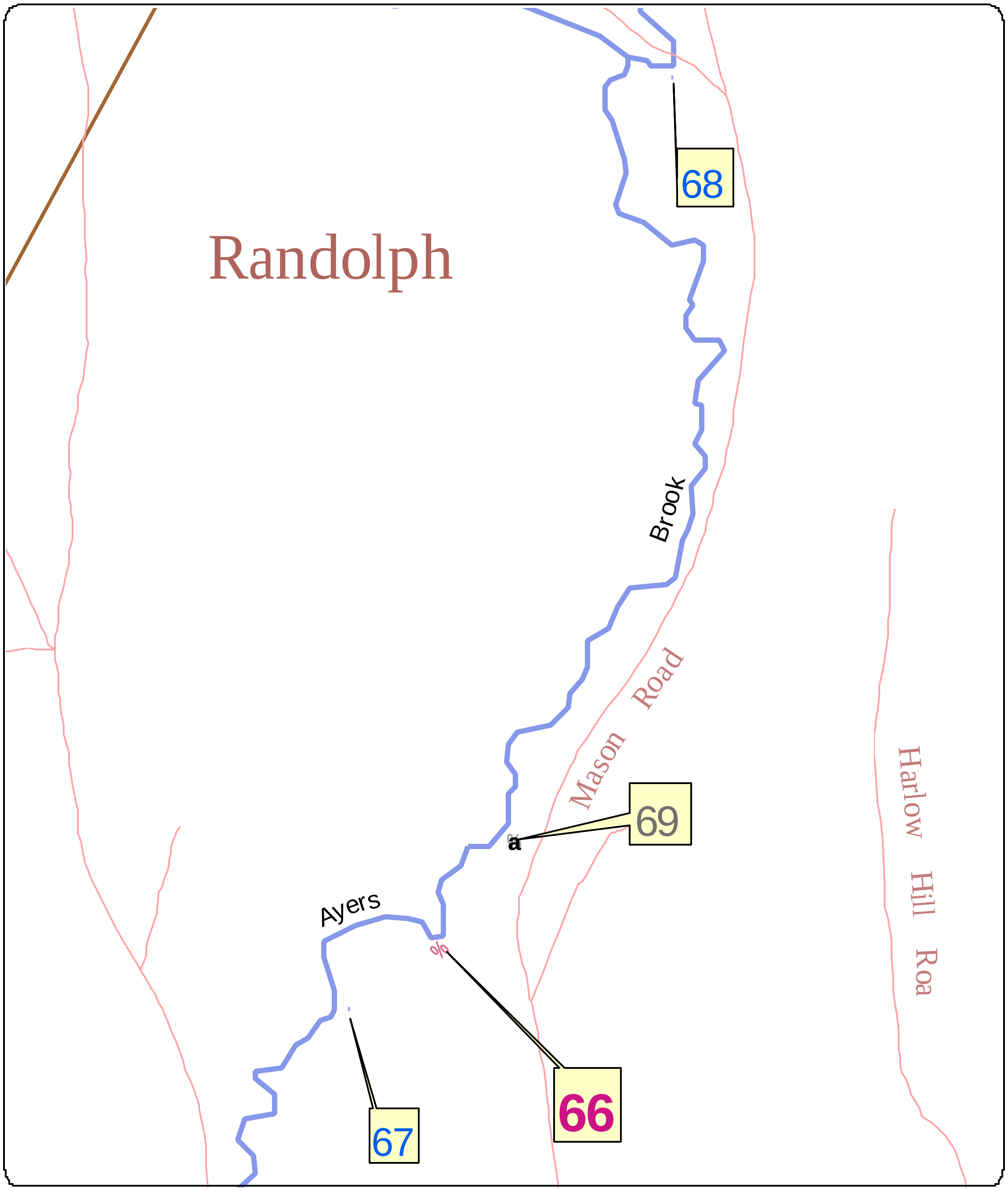
Streambank Erosion Inventory
Third Branch of the White River
Sites 52 - 64



N
W E
S

Approximate Scale is 1: 11,000

Figure B7



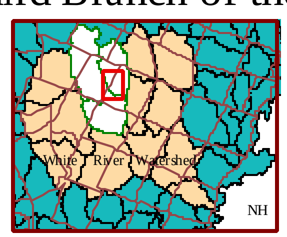
Legend

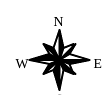
Streambank Erosion Severity

- a Rip-rap
- Low
- & Moderate
- % High
- $ Very High

- Streams
- Roads
- Towns
- Third Branch Subwatersheds
- White River Watershed
- Vermont Subwatersheds

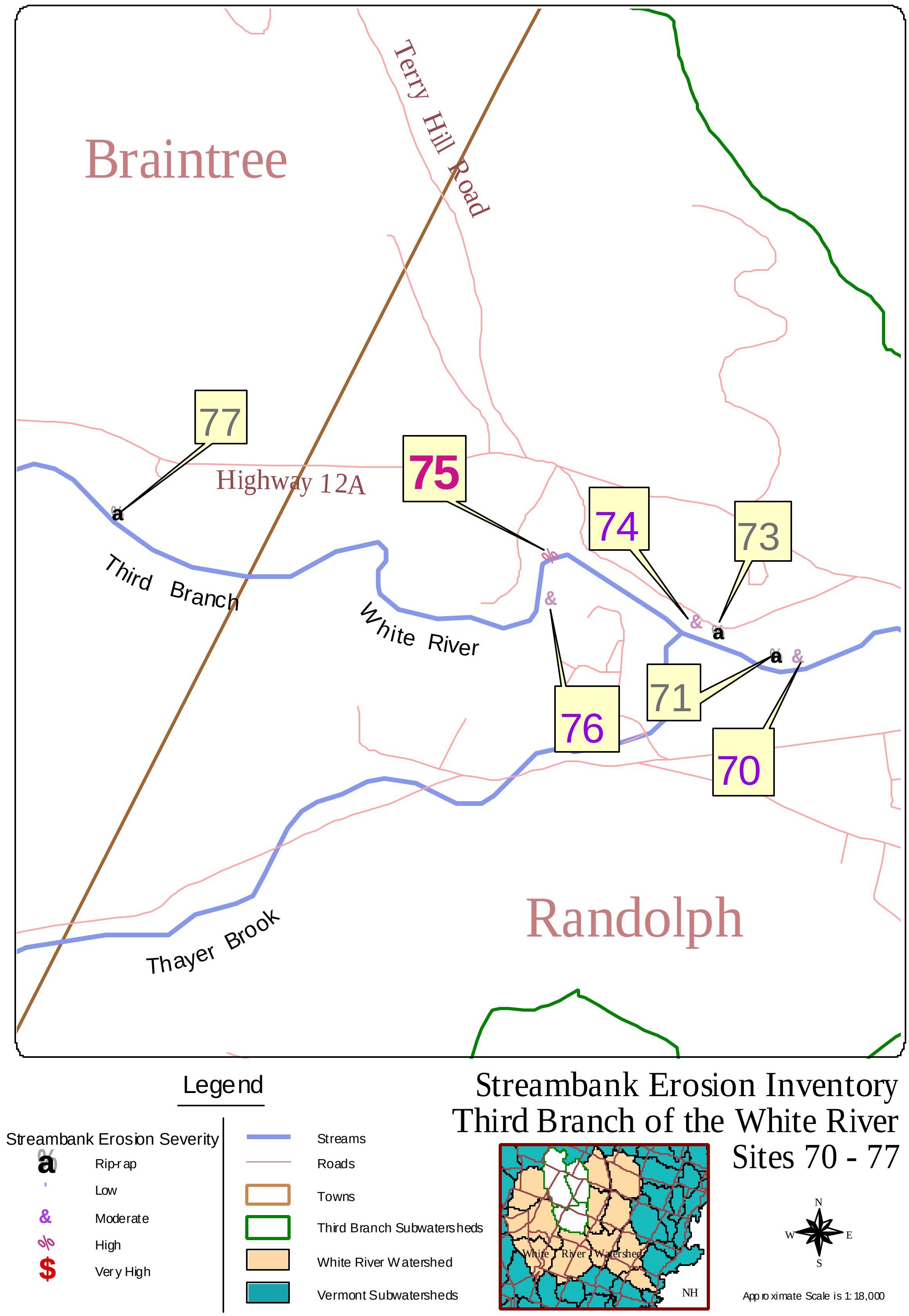
Streambank Erosion Inventory
Third Branch of the White River
Sites 66 - 69





Approximate Scale is 1: 17,000

Figure B8



Braintree
Terry Hill Road
Highway 12A
77
75
74
73
71
76
70
Third Branch
White River
Thayer Brook
Randolph
Legend
Streambank Erosion Severity
a Rip-rap
Low
& Moderate
% High
$ Very High
Streams
Roads
Towns
Third Branch Subwatersheds
White River Watershed
Vermont Subwatersheds
Streambank Erosion Inventory
Third Branch of the White River
Sites 70 - 77
White River Watershed
NH
N
W
E
S
Approximate Scale is 1: 18,000

APPENDIX C (Sediment Budget Computations)

Sediment Budget - Ayers Brook

Sheet and Rill Erosion Estimate – Ayers Brook

Land Use Type	Acres	Assumed Erosion Rate	Tons/Year eroded	Delivery Ratio	Delivered
Forest	16,603	0.1 ton/acre/yr	1,660	0.20	332
Hayland and pasture	3,557	0.1 ton/acre/yr	355	0.20	71
Cropland (mostly rowcrop corn)	2,368	2.0 ton/acre/yr	4,736	0.20	947
Non-Eroding	1,184	0	0	0	0
Total	23,707		6751		**1350 Tons Per Year**

Dirt Road Surface Erosion Estimate - Ayers Brook

Assumptions:

41 miles of dirt surface roads

50% of the roads or 20.5 miles erode @ 10 tons/year
50% of the roads or 20.5 miles erode @ 5 tons/year

Based on field measurement; dirt road surface averages 18 feet wide

Based on field observation, it is estimated that about 50% of the eroded soil reaches the stream.

Road Length (Miles)	Road Width (Feet)	Estimated Erosion Rate (Tons/Acre/Yr)	Total Eroded (Tons/Year)	Delivery Ratio	Delivered (Tons/Year)
20.5	18	5	225	0.5	113
20.5	18	10	450	0.5	225
Total			675		@ **340 Tons/Yr**

Streambank Erosion Estimate - Ayers Brook

Erosion estimates made during the stream classification in 1998 were based on an assumed stream length of 12 miles. The actual length measured by GIS is 10.9 miles. The 4220 tons calculated in 1998 was therefore prorated to 91% or 3840 tons of soil eroded from Ayers Brook streambanks.

Stream Length 10.9 miles
Streambank Heights 4 -10 ft
Bank Recession Rates 0.05ft/yr - 0.6 ft/yr
Unit weight of soil is 80 lbs/ft^3
Delivery ratio 85%

The total amount delivered to the stream system: 3840 x 0.85 = **3264 Tons Per Year**.

Sediment Budget Total - Ayers Brook

Sheet and Rill Erosion		**1350 Tons Per Year**
Dirt Road Surface Erosion		**340 Tons Per Year**
Streambank Erosion		**3264 Tons Per Year**
	Total	**4954 Tons Per Year**

Sediment Budget - Third Branch (Excluding Ayers Brook)

Sheet and Rill Erosion Estimate - Third Branch (Excluding Ayres Brook)

Land Use Type	Acres	Estimated Erosion Rate (Tons/Acre/Yr)	Total Eroded (Tons/Year)	Delivery Ratio	Delivered (Tons/Year)
Forest	57,568	0.1	5,757	0.2	1,152
Hayland and pasture	3,200	0.1	320	0.2	64
Cropland (mostly row crop corn)	1,600	2.0	3,200	0.2	640
Non-Eroding	1,632	0	0	0	0
Total	64,000		9,277		**1856 Tons Per Year**
*Third Branch Upstream of Randolph (Excluding Ayers Brook) 0.58 x 1856 =					**1076 Tons Per Year**
*Third Branch Downstream of Randolph 0.42 x 1856 =					**780 Tons Per Year**

* For purposes of erosion data summary tabulation in the main report (Table 8 - Sediment Budget Data Summary) the above erosion total is divided into two parts on the basis of drainage area for "Third Branch upstream of Randolph (Excluding Ayers Brook)" and "Third Branch downstream of Randolph".

Dirt Road Surface Erosion Estimate -Third Branch (Excluding Ayers Brook)

78 miles of dirt surface roads

50% of the roads or 39 miles erode @ 10 tons/year
50% of the roads or 39 miles erode @ 5 tons/year

Based on field measurement; dirt road surface averages 18 feet wide

Based on field observation, it is estimated that about 50% of the eroded soil reaches the stream.

Road Length (Miles)	Road Width (Feet)	Estimated Erosion Rate (Tons/Acre/Yr)	Total Eroded (Tons/Year)	Delivery Ratio	Delivered (Tons/Year)
39	18	5	425	0.5	213
39	18	10	850	0.5	425
			1,275		
				Total	**640 Tons Per Year**
*Third Branch Upstream of Randolph (Excluding Ayers Brook) 0.58 x 640 =					**371 Tons Per Year**
*Third Branch Downstream of Randolph 0.42 x 640 =					**269 Tons Per Year**

- For purposes of erosion data summary tabulation in the main report (Table 8 - Sediment Budget Data Summary) the above erosion total is divided into two parts on the basis of drainage area for "Third Branch upstream of Randolph (Excluding Ayers Brook)" and "Third Branch downstream of Randolph".

Streambank Erosion Estimate - Tributaries to Third Branch

Assumptions for calculations

Unit weight of all soils is 80-lbs/ ft^3
Assume 50% of streambanks are 3' high, in Tunbridge soils and receding @ .05 ft/yr
Assume 50% of streambanks are 5' high, in Merrimac soils and receding @ 0.1 ft/yr
Tributary Streambank miles above Ayers Brook on the 3rd Branch = 239,346ft or 45.33 miles.
Estimate:14.96 miles or 1/3 of streambanks contribute negligible amounts of sediment.
Therefore, 30.37 miles are actively eroding,
Estimate bank recession @ 0.1 ft/yr
½ or 15.185 mi are 5 ft high banks, receding at 0.1 ft/yr

$$\frac{5\text{ ft high} \times 5280\text{ ft/mi} \times 0.1\text{ ft/yr} \times 80\text{ lbs/ft}^3}{2000\text{ lbs/ton}} = 105.6\text{ tons/bank mile/yr}$$

105.6 tons/bank mile x 15.185 bank miles = 1604 tons eroded

1604 tons x Delivery Ratio of 0.85 = 1363 tons/yr Delivered

½ of the streambanks are 3 feet high receding @ 0.1 ft/yr

$$\frac{3\text{ ft high} \times 5280\text{ ft/mi} \times 0.1\text{ft/yr} \times 80\text{ lbs/ft}^3}{2000\text{ lbs/ton}} = 63.36\text{ tons/bank mile/yr}$$

63.36 tons x 15.185 = 962 tons/yr eroded

Apply 0.85 delivery ratio

0.85 x 962 tons = 818 tons/yr delivered

Total = 1363 + 818 = **2181 Tons Per Year.**

Streambank Erosion Estimate - Third Branch upstream of Randolph (Main Stem)

Total Length: 92,027 ft or 17.43 miles
Estimate 1/3 is non–eroding leaving the remaining 11.5 miles
Of those miles:
½ or 5.75 miles are 5 ft high eroding @ 0.1 ft/yr
½ or 5.75 miles are 3 ft high eroding @ 0.05 ft/yr

$$\frac{5\text{ ft high} \times 5280\text{ ft/mi} \times 0.1\text{ft/yr} \times 80\text{ lbs/ft}^3}{2000\text{ lbs/ton}} = 105.6$$

105.6 x 5.75 = 607.2 tons eroded

607.2 x 0.85 Delivery Ratio = 516 tons/yr delivered

$$\frac{3\text{ ft high} \times 5280\text{ ft/mi} \times 0.05\text{ ft/yr} \times 80\text{ lbs/ft}^3}{2000\text{ lbs/ton}} = 31.68\text{ tons/mi}$$

31.68 x 5.75 = 182 tons

182 x 0.85 = 155 tons delivered

Total = 516 + 155 = **671 Tons Per Year**

Streambank Erosion Estimate - Third Branch downstream of Randolph (Main Stem)

Total Miles:		11.63
Miles eroding "Very High"	banks = 15 ft High	= 0.3 miles
Miles eroding "High"	banks average 8 ft High	= 0.95 miles
Miles eroding "Moderate"	banks average 5 ft High	= 0.99 miles
Miles eroding "Low"	banks average 4 ft High	= 0.15 miles
Miles eroding @ Geologic rate	banks average 4 ft High	= 9.23 miles

<u>Eroding Banks "Very High"</u>

$$\frac{15 \text{ ft} \times 5280 \text{ ft/mi} \times 1.5 \text{ ft/yr} \times 80 \text{ lbs/ft}^3}{2000 \text{ lbs/ton}} = 4752 \text{ tons/mi}$$

4752 tons/mi x 0.3 mi = 1426 tons

1426 tons x Delivery Ratio 0.90 = 1283 Tons Per Year

<u>Eroding Banks "High"</u>

$$\frac{8 \text{ ft} \times 5280 \text{ ft/mi} \times 1.0 \text{ ft/yr} \times 80 \text{ lbs/ft}^3}{2000 \text{ lbs/ton}} = 1690 \text{ tons/mi}$$

1690 x 0.95 mi = 1606 tons

1606 tons x delivery ratio of 0.90 = 1445 Tons Per Year

<u>Eroding Banks "Moderate"</u>

$$\frac{5 \text{ ft} \times 5280 \text{ ft/mi} \times 0.5 \text{ ft/yr} \times 80 \text{ lbs/ft}^3}{2000 \text{ lbs/ton}} = 528 \text{ tons/mi}$$

528 tons/mi x 0.99 mi =523 tons x 0.90 Delivery Ratio = 470 Tons Per Year.

<u>Eroding Banks "Low"</u>

$$\frac{4 \text{ ft} \times 5280 \text{ ft/mi} \times 0.5 \text{ ft} \times 80 \text{ lbs/ft}^3}{2000 \text{ lbs/ton}}$$

422.4 tons/bank mi x 0.15mi = 63.36 tons x 0.90 Delivery Ratio = 57 Tons Per Year

<u>Eroding banks "Geologic Rate"</u>

$$\frac{4 \text{ ft} \times 5280 \text{ ft/mi} \times 0.15 \text{ ft} \times 80 \text{ lbs/ft}^3}{2000 \text{ lbs/ton}}$$

127 tons/bank mi x 9.23 bank miles = 1172 tons

1172 tons x 0.90 delivery ratio = 1055 Tons Per Year

Total = 1283 + 1445 + 470 + 57 + 1055 = **4310 Tons Per Year**